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中节能咨询有限公司
CECEP Consulting Co.,Ltd.

绿色产业智库 | Green Industry Think Tank

中节能咨询有限公司是中国节能环保集团公司所属专业从事节能环保综合性咨询服务的全资子公司，同时也受集团公司委托，承担“中国节能环保集团公司产业研究中心 ”这一产业智库的建设任务。公司自 2002 年底成立伊始，就肩负着在节能环保领域为包括中央和各级地方政府提供咨询服务的使命，同时也面向国内外各类企事业单位、国际机构提供优质专业化咨询服务。

近年来，公司完成数百项各级政府及国际机构委托的政策、课题及规划研究项目，同时在火电热电、市政热力燃气、城市固废处理、污水处理、生态建设和环境工程、工业节能、建筑节能和新能源等领域开展了大量项目咨询。

公司累计开展咨询服务 6500 余项，项目涉及投资额超过 9000 亿元，在中国节能环保领域具有很高知名度和良好声誉，被誉为节能环保领域的 “智库 ”。由于成绩显著，公司被发改委、财政部和环保部评为 “十一五” 节能减排先进单位。

自 2009 年起，公司受集团公司委托，具体承担国资委 “中央企业节能减排监测中心” 的建设、运维任务，对于我们的出色服务，国资委综合局每年都给集团致信表示感谢。

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我们获得的荣誉 | Awards & Recognitions

- 《黑龙江紫金铜业有限公司铜冶炼项目节能评估报告》荣获“2017年度黑龙江省优秀工程咨询成果一等奖”
- 《蕉岭县生活污水处理设施全县捆绑PPP项目》荣获“2016-2017年度广东省优秀工程咨询成果一等奖”
- 《大观净水厂可行性研究报告技术审查报告》荣获“2016-2017年度广东省优秀工程咨询成果三等奖”
- 《湖北华电江陵发电厂一期工程项目申请报告评估报告》荣获“2016 年湖北省优秀工程咨询成果二等奖”
- 《大别山电厂二期2x660MW扩建工程项目申请报告评估报告》荣获“2016年湖北省优秀工程咨询成果优秀奖”
- 荣获国家开发银行信息科技局颁发的“2015年度优秀合作伙伴”
- 《基于环境管理战略转型的产业支撑能力案例评估》荣获“2015 年度北京市优秀工程咨询成果一等奖”
- 《绿色信贷节能环保效益评价系统》荣获“2015 年度北京市优秀工程咨询成果三等奖”

Scopes Of Business | 我们专注的业务

01 Policy and Research Analysis
政策与专题研究

受政府部门、国际机构及企事业单位委托,开展节能、环保、低碳、新能源等领域的政策法规、技术标准、行业规范的研究制定,以及行业现状、发展动态与趋势、投资机会、综合解决方案等方面的专题研究。

02 Planning Consulting
规划咨询

行业发展、区域节能环保、循环经济、低碳发展、新能源开发利用、热电联产、绿色发展、空间、环境、节水等专项规划的编制。

03 Green Financial Services
绿色金融服务

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04 Engineering Consulting
工程咨询

投资机会研究、项目建议书及可研的编制与评估、固定资产投资项目节能评估与审查、项目核准(资金)申请报告编制与评估、初步设计概算审查、融资方案咨询、项目后评价。

05 Third-party Services
第三方业务

作为政府和企业之间的独立第三方,提供包括能源审计、清洁生产审核、节能量审核、碳核查等在内的专业服务。

06 Technology Dissemination
技术推广

主要承担节能、低碳、环保技术推广政策咨询,行业共性技术市场研究,审核、碳核查等在内的专业服务。

07 Information System Services
信息系统开发

为各级政府部门、企业设计开发节能环保综合信息化管理系统,为金融机构开发绿色金融项目环境效益评估系统。

恒有源科技发展集团有限公司
EVER SOURCE SCIENCE &TECHNOLOGY DEVELOPMENT GROUP CO.,LTD.

恒有源科技发展集团有限公司（简称恒有源集团），是中国节能环保集团公司旗下的中国地热能产业发展集团有限公司（香港上市号 8128.HK，简称中国地热能）在北京的科技实业发展总部。

Ever Source Science and Technology Development Group Co. Ltd. (HYY Group) is the Beijing Head Office for science and technology development owned by China Geothermal Industry Development Group Ltd. (HKEx: 08128, China Geothermal) which is subordinate to the China Energy Conservation and Environment Protection Group.

在京港两地一体化管理框架下，恒有源集团专注于开发利用浅层地能（热）作为建筑物供暖替代能源的科研与推广；致力于原创技术的产业化发展；实现传统燃烧供热行业全面升级换代成利用浅层地能为建筑物无燃烧供暖(冷)的地能热冷一体化的新兴产业;利用生态文明建设成果,促进传统产业升级换代;走出中国治理雾霾的新路子。

With integrated administrative framework of Beijing and Hong Kong offices, the HYY Group is fully engaged in the R&D and market promotion of using shallow ground source (heat) energy as the substitute energy source of heating for buildings; in industrialized development of its original technology; to the upgrading of traditional heating industry into a new industry of integrated combustion-free heating and cooling with ground source energy; and in pioneering ways to improve ecological construction and curb haze in China.

- **员工行为准则：**
  Code of Conduct :

  安全第一，标准当家
  With safety first, standard speaks

  扎扎实实打基础，反反复复抓落实
  To form a solid foundation, to make all strategies practicable

  负责任做每件事，愉快工作每一天
  All develop sense of responsibility,and achieve pleasure at work

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- **我们的宗旨：** 求实、创新
  Our Mission: Pragmatism and Innovation
- **我们的追求：** 人与自然的和谐共生
  Our Pursue: Harmonious Coexistence of Human and Nature
- **我们的奉献：** 让百姓享受高品质的生活
  Our Dedication: Improve comfort level of the people’s livelihood
- **我们的愿景：** 原创地能采集技术实现产业化发展——让浅层地能作为建筑物供暖的替代能源；进一步完善能源按品位分级科学利用；在新时期，致力推广利用浅层地能无燃烧为建筑物智慧供暖（冷）；大力发展地能热冷一体化的新兴产业。
  Our Vision: Work for greater industrialized development of the original technology for ground source energy collection, while promoting the use of shallow ground energy as the substitute energy of heating for buildings; furthering scientific utilization of energies by grades; propelling combustion-free intelligent heating (cooling) for buildings with ground source energy; and forcefully boosting the new industry of integrated heating and cooling with ground source energy.

中國地熱能
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本期焦点

CURRENT FOCUS

中国恒有源主要致力于发展清洁能源产业：氢能＋地能（热），提供环境系统设计方案和成套产品。旗下的中氢新能，是专业从事氢燃料电池电堆、动力系统研发、生产、销售的企业，提供氢燃料电池产品在零碳绿色交通、物流及分布式能源（CHP）等领域的解决方案。

封面 / 目录图片 供图：张捷

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编者言

今年十月，中国恒有源发展集团有限公司签约并购中氢新能（深圳）新技术有限公司，使中国恒有源发展集团有限公司的清洁能源系统集成的产业定位增加了氢燃料电池动力系统研发与生产的内容，扩展了清洁能源在可移动系统中的应用。正如习近平主席在 2023 年 11 月 16 日亚太经合组织工商领导人峰会上的书面讲话中指出的：近年来，中国新能源汽车、锂电池、光伏产品“新三样”出口快速增长，即将启动的全国温室气体自愿减排交易市场将创造巨大的绿色市场机遇。我们将加快推进现代化产业体系建设，为各类经营主体共享发展成果提供更好制度性保障，不断培育新的增长动能、释放更大发展空间。

中国恒有源发展集团有限公司签约并购中氢新能（深圳）新技术有限公司

CHYY DEVELOPMENT GROUP LIMITED ENTERED INTO AN AGREEMENT TO ACQUIRE CHINA HYDROGEN ENERGY（SHENZHEN）NEW TECHNOLOGY CO., LTD.

作者：苏海龙、何天悦

中国恒有源发展集团有限公司（以下简称中国恒有源）于二零二三年十月二十七日与中氢新能（深圳）新技术有限公司（以下简称中氢新能）订立协议，中国恒有源有条件收购中氢新能，占该公司全部已发行股本的 80%，最高总代价为 70,200,000 港元。成交后，中氢新能将成为中国恒有源的非全资附属公司，而目标集团的财务资料将并入中国恒有源财务报表内。

1 中国恒有源发展集团有限公司

中国恒有源主要致力于发展清洁能源产业：氢能 + 地能（热）。产业发展目标是以不高于传统能源的成本，替代化石能源的燃烧。实现在最恶劣气候条件下稳定保证人们舒适生活、动植物生存生长的电能和所在的环境空间需要的适宜温度。为不同气候区域的建筑提供与之相匹配的环境系统设计方案和成套产品。是清洁能源系统集成商。

2 中氢新能（深圳）新技术有限公司

中氢新能生产的氢燃料电池，在大功率、长续航上优势明显，尤其在恶劣气候条件下，更显现出不可替代的优势。

3 中国恒有源发展集团有限公司与中氢新能（深圳）新技术有限公司联合亮相香港国际环保展

2023 年国际环保博览于 10 月 26 日至 29 日在香港亚洲国际博览馆（亚博馆）举行，中国恒有源与中氢新能联合亮相参展。

本届博览会将以「绿色跃动：创建零碳未来」为主题，云集来自中国内地及海外的环保领域领军企业，推广减碳、循环经济及新能源等不同的环保概念，产品展示内容涵盖绿色建筑及能源效益、绿色运输、绿色金融以及环境、社会及管治（ESG）等领域。

中国恒有源与中氢新能联合亮相香港国际环保展

中国恒有源主要致力于发展清洁能源产业：氢能＋地能（热）。以不高于传统能源成本，替代化石能源的燃烧，实现在最恶劣气候条件下稳定获取保证人们舒适生活、动植物生存生长的电能和所在空间需要的适宜温度，提供环境系统设计方案和成套产品。中氢新能是专业从事氢燃料电池电堆、动力系统研发、生产、销售的企业，提供氢燃料电池产品在零碳绿色交通、物流及分布式能源（CHP）等领域的解决方案。

展会期间，中国工程院武强院士莅临公司展台，详细了解了氢能及氢燃料电池技术积累及产品应用，并对“氢能＋地能（热）”的发展路线给予了充分的肯定。他表示，提升氢能与清洁能源开发与利用，是实现绿色低碳转型的重要途径之一，是践行“双碳”战略目标与可持续发展战略的重要举措。

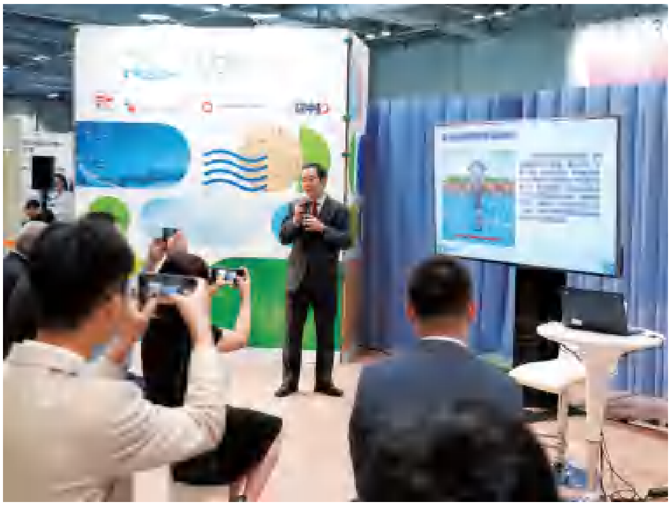
本届展会上展示了中氢新能自主技术产品120KW 氢燃料电池动力系统产品，吸引了众多参展嘉宾前来咨询参观。该产品核心零部件国产化率达到 100%，并经过长时间、多领域、不同应用场景批量市场化验证，其安全性、可靠性、耐久性等各项指标均受到用户一致肯定。

展会同期，中国恒有源行政副总裁何天悦进行了主题演讲，重点介绍了集团公司核心技术产品、市场应用案例等。他表示，中国恒有源在拓展自有业务的同时，也将积极布局氢能应用领域，打造零碳、绿色、智慧能源系统服务方案，逐步完善“发展和利用与传统能源成本相当的绿色替代能源”的应用技术方向，逐步实现“发展可再生能源领域的替代传统化石能源产业：氢能＋地能（热）”的企业愿景。

此后，中氢新能市场总监苏海龙介绍了国内

展会同期交流

中国工程院武强院士莅临公司展台



中国恒有源行政副总裁何天悦进行主题演讲

中氢新能市场总监苏海龙主持全球首款大功率氢燃料电池产品发布

外氢能及燃料电池汽车产业发展现状，中氢新能公司核心技术产品，并主持发布了中氢新能全球首款自主研发的面向高海拔、高寒地区重载运输领域大功率氢燃料电池动力系统产品发布会。

该产品额定功率为150KW，主要适用于重型卡车、工程机械、冷热电三联供分布式能源等领域，突破了氢燃料电池重型卡车长续航、高功率和长寿命的关键技术，能够持续稳定运行于海拔3000m，温度 -30-85°C环境下等低温、高海拔场景，系统额定质量功率密度为647.5W/kg，使用寿命超过 15000 小时。

经过大量的路测与验证，搭载该款氢燃料电池动力系统产品的全球首款适用于高海拔、高寒地区，不同路况、不同季节和环境温度下的 49T 重型卡车已成功研发，并通过了国家工信部公告。未来我们将计划在新疆地区进行批量交付，打造氢能重卡运输示范专线，助力地区实现“双碳”目标。

多种路况下，整车及氢燃料电池动力系统稳定性、适应性测试

北京市海淀外国语实验学校京北校区单井循环换热地能采集技术实例研究

——2023 年世界地热大会入选论文

A CASE STUDY OF SHALLOW GEOTHERMAL HEATING AND COOLING THE APPLICATION OF SINGLE-WELL CIRCULATION HEAT EXCHANGE GEOTHERMAL ENERGY ACQUISITION TECHNOLOGY IN HAIDIAN FOREIGN LANGUAGE SCHOOL IN BEIJING AND HEBEI CAMPUS

—— Paper presented at the 2023 World Geothermal Congress

作者：徐生恒、汪集旸、杨明忠、李大秋

摘　要：恒有源科技发展集团有限公司发明的“单井循环换热地能采集技术”是高效安全采集浅层地热能为建筑物提供稳定热源的一种方式。本文介绍了北京海淀外国语实验学校 20 年来应用此技术持续供暖的成果。2019 年起该校在位于北京冬奥会张家口赛区的京北新校区项目上扩大应用，满足新校区 13.7 万㎡建筑包括各种冬季运动场馆的供暖 / 制冷及全年提供生活热水的需求。使可再生能源利用率达 60% 以上，年减排二氧化碳超过 1976t。本项目应用“单井循环换热地能采集技术”获取可再生浅层地热能，

不消耗不污染地下水，实现区域零碳排放。针对校区建筑分散和使用功能的特点，设置为集中采能、分布式设置冷热源站的水环热泵系统，进一步实现系统节能。利用季节蓄能实现热能的夏储冬用，供暖及制冷都达到了高能效比运行。本文是 2003 年国际地热大会徐生恒和 Ladislaus Rybach 发表的《浅层地能资源利用——单井抽灌技术的实例研究》一文的延续。长期持续稳定的运行证明了单井循环换热地能采集技术的可靠性并具有简单可复制性及广泛的适应性。是建筑供暖领域实现“碳中和、碳达峰”目标的一种优选的技术方案。

关键词：浅层地热能；单井循环换热

引 言

浅层地热能是指蕴藏于地表以下约 200 米以内的热能，温度低于 25 度 [1]。浅层地热能具有分布广、埋深浅、储量大和开发利用成本低等特点，是地热能家族中的重要组成部分。采用先进的单井循环换热地能采集技术能够大规模、低成本稳定地开发利用浅层地热能。结合热泵技术实现其热能品位（温度）的提升，使其成为建筑供暖的替代能源，是解决建筑供暖的便捷的低碳路径。2003 年徐生恒先生和瑞士苏黎世大学吕贝克教授以北京海淀外国语实验学校为实例联合发表了《浅层地能资源利用——单井抽灌技术的实例应用》一文，首次介绍了利用单井循环换热地能采集技术开发利用浅层地热能为建筑物供暖 / 冷的工程实例。由于采用单井循环技术从而避免了回灌难和地下水资源的污染、浪费等问题引起大会重视。此后也不断有业内人士问询，如今 20 多年过去了海淀外国语实验学校先后完成了两次扩建，浅层地热能用于供暖在中国也有了迅猛的发展，单井循环换热技术已经推广应用了超过 2000 万平方米建筑。本文以当年研究的样本工程——北京海淀外国语实验学校的供暖 / 冷系统最新进展为例，介绍了单井循环换热地能采集技术不断创新的成果和取得的经济效益及环境效益，以回应关心中国浅层地热能开发利用和单井循环换热技术的朋友们。

1. 单井循环换热地能采集技术简介

图 1 是单井循环换热地能采集井示意图。井内的上密封装置和下密封装置将井管分为三个区，从上向下分别是加压回水区，密封区和抽水区。井水由置于底部抽水区的潜水泵抽出进入热泵机组放热（采暖）或吸热（制冷）后由热泵机组返回进入上部的加压回水区，通过花管流出地能采集井外与周围岩土体进行热交换后通过井管下部的花管进入井内，再由潜水泵抽出。上述抽水区和加压回水区应在同一水层内，实现同层回灌 [2]。

单井循环换热地能采集井可以实现 100% 同

井同层回灌，规避了异井回灌普遍存在的回灌难的问题。单井循环换热地能采集井夏季将建筑物的热量排放储存到地下;冬季将夏季储存的热量取出为建筑物供暖,实现了采集井周边地下温度场的冬夏平衡（图 2)。

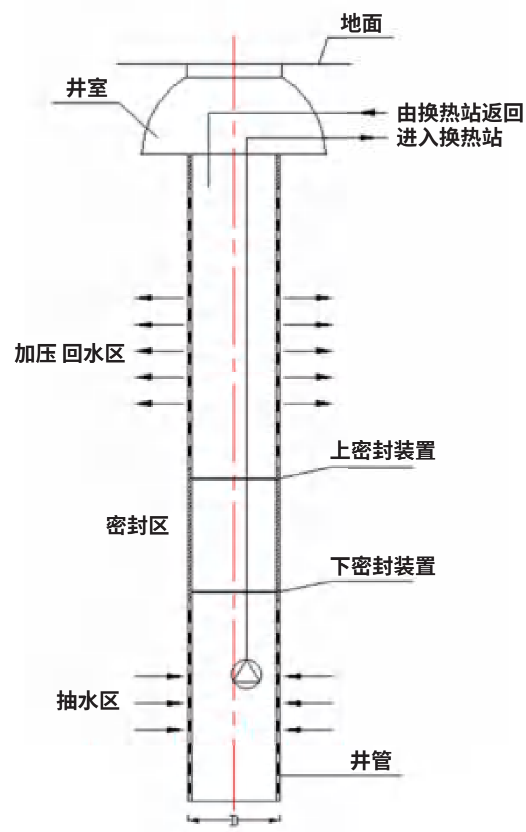


图 1 单井循环换热地能采集井示意

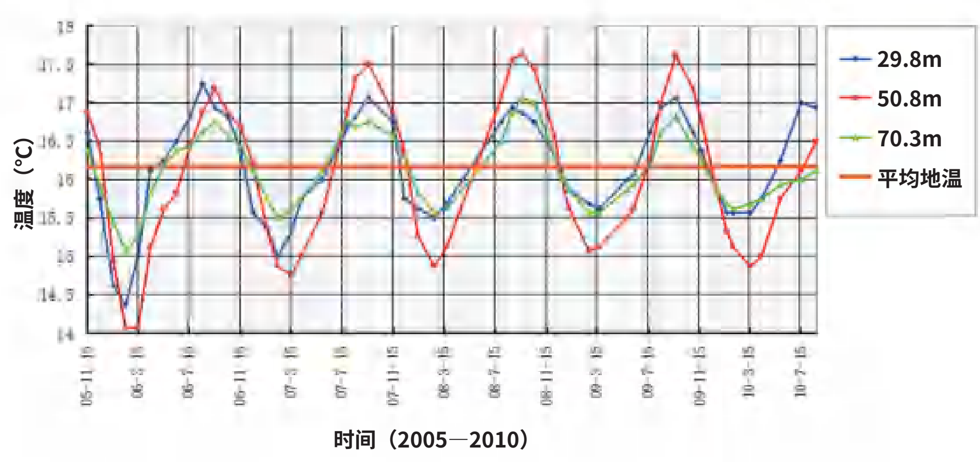


图 2 某工程师宿舍群采集井周边地下温度变化曲线

北京市水环境监测中心连续 16 年对单井循环换热地能采集井水质进行跟踪监测，并对水体的 21 项指标进行了分析，确认水体质量在出水和回灌水中除水温外均没有明显的变化，单井循环换热地能采集井未对地下水质量造成影响。经专家评审单井循环换热技术不消耗也不污染地下水，因此对地下水体质量是安全的 [3]，可以用来大规模、安全、高效和稳定的采集浅层地热能。

2. 海淀外国语实验学校概况

北京海淀外国语实验学校北校区工程为学校的一期工程，总建筑面积约 6 万㎡。北京海淀外国语实验学校南校区工程为学校的二期工程，总建筑面积约 4 万㎡。京北校区是学校的三期工程，位于冬奥之城张家口市，张家口地区属寒冷地区，其室外气象参数详见表 1。工程 2019 年开始建设，2022 年全部建成。京北校区建筑面积 13.7 万㎡，是新建的可容纳 5000 名学生 12 年一贯制国际化学校，包含教学楼、办公楼、科研中心、“海外”艺术学院、“海外”剧场、教职工食堂、学生公寓、教师公寓、室内外运动场馆等 10 栋建筑，项目各建筑的冷热负荷详见表 2。项目是北京 2022 年冬奥会和冬残奥会奥林匹克教育示范学校及国家体育总局为奥运储备中国国少队人才的冰雪项目基地。

表 1 张家口室外气象参数

台站位置	北纬	40° 47′
	东经	114° 53′
	海拔（m）	723.9
大气压力（mbar）	冬季	938.9
	夏季	924.4
年平均温度°C		7.8
室外计算 (干球) 温度 (°C)	冬季	-15
	夏季	31.6
室外计算 (湿球) 温度 (°C)		22.3
最热月平均温度 (°C)		23.2

表 2 建筑物冷热负荷表

序号	建筑物名称	面积（㎡）	设计冷负荷		设计热负荷		设计热水负荷 (kw)	冬季温度（°C）		夏季温度（°C）	
			冷指标 (w/ ㎡)	冷负荷 (kw)	热指标 (w/ ㎡)	热负荷 (kw)		冬季室内设计温度 (°C)	冬季室内实际温度 (°C)	夏季室内设计温度 (°C)	夏季室内实际温度 (°C)
1	1# 小学部	19731.65	65	1282.56	70	1381.22	890	18 ～ 24	19-22	22 ～ 26	22-24
2	2# 中学部	19731.65	65	1282.56	70	1381.22	890	18 ～ 24	19-22	22 ～ 26	22-24
3	3# 海外剧场	7473.8	65	485.8	75	560.54	0	18 ～ 24	19-22	22 ～ 26	22-24
4	4# 综合体育中心	4470.04	80	357.6	90	402.3	0	18 ～ 24	19-22	22 ～ 26	22-24

序号	建筑物名称	面积（㎡）	设计冷负荷		设计热负荷		设计热水负荷（kw）	冬季温度（℃）		夏季温度（℃）	
			冷指标（w/㎡）	冷负荷（kw）	热指标（w/㎡）	热负荷（kw）		冬季室内设计温度（℃）	冬季室内实际温度（℃）	夏季室内设计温度（℃）	夏季室内实际温度（℃）
5	滑雪厅	3327.33	80	266.19	90	299.46	0	18～24	19-22	22～26	22-24
6	5# 冰雪中心	4558.46	80	364.68	90	410.26	293	18～24	19-22	22～26	22-24
7	6# 国际部高中	30456.21	65	1979.65	70	2131.93	890	18～24	19-22	22～26	22-24
8	7# 国际部初中	29849.06	65	1940.19	70	2089.43	890	18～24	19-22	22～26	22-24
9	8# 幼儿园	14253.35	75	1069	80	1140.27	197	18～24	19-22	22～26	22-24
10	11# 后勤办公楼	3564.93	75	267.37	80	285.19	141	18～24	19-22	22～26	22-24
11	**总计**	**137416.48**		**9295.59**		**10081.82**	**4191**				

目前京北校区共有 10 栋建筑，由于校园面积比较大，具有建筑物分散、地表高程差比较大、使用时间及频率不一等特点，选用恒有源浅层地热能分布式冷热源系统，为建筑物供暖 / 冷和生活热水。系统由单井循环换热地能采集井、浅层地热能集中换热站、分布式冷热源站及建筑物室内的末端系统组成。

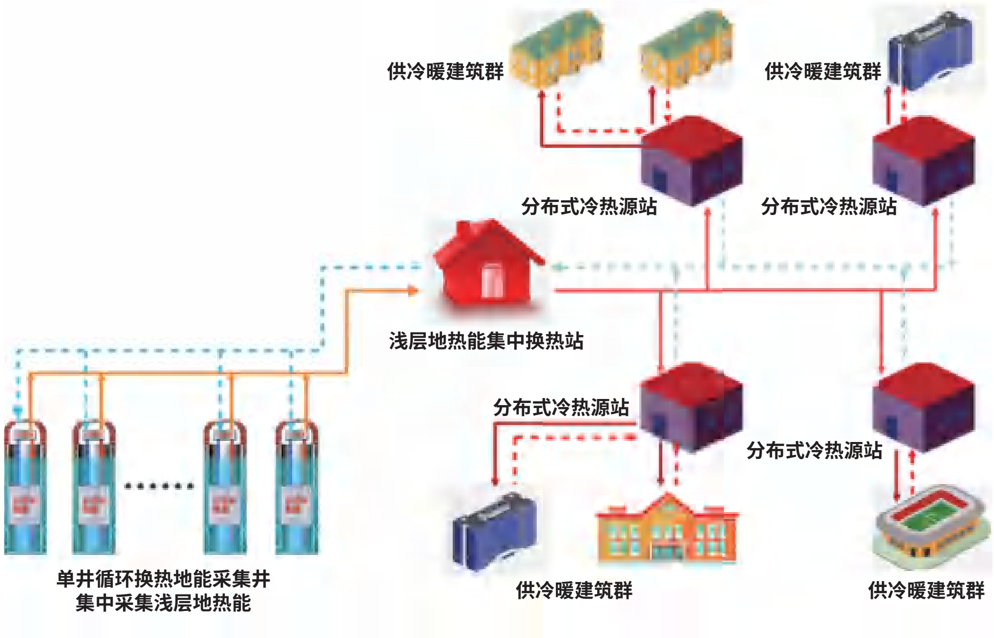


图 3　恒有源浅层地热能分布式冷热源系统原理

如图 3 所示，设置多口单井循环换热地能采集井集中采集浅层地热能，将采集井连接到一起形成一次采集管网，利用一次采集管网将浅层地热能输送至集中换热站，由二次换热管网将浅层地热能分配至分布式冷热源站，分布式冷热源站内设置能量提升三次管网，提升至供暖或降低到制冷的温度品位，由四次管网输送至供暖冷建筑群，完成供暖冷。

3. 地能采集井设计

根据项目所在地的地层岩性，采集井设计为无换热颗粒采集井形式[2]，井深 117m，开孔 194mm，终孔 194mm（图 4）。项目创新的采用了恒有源潜孔锤跟管一次成井技术，与项目一期的冲击钻成井技术相比，新的成井技术有效的提高了钻井效率，降低了施工成本。采集井成井后对采集井进行了测试，采集井静水位埋深 63m，动水位 72m，出水量 $44m^3/h$，循环水量 $50m^3/h$，冬季运行期间采集井供水温度 15°C，回水温度 10°C。根据地能采集井额定供热（冷）功率公式：N=1.16 × Q × |T2 - T1|[2]，项目采集井的换热功率为 : N=1.16 ×50 ×|15-10|=290kW。

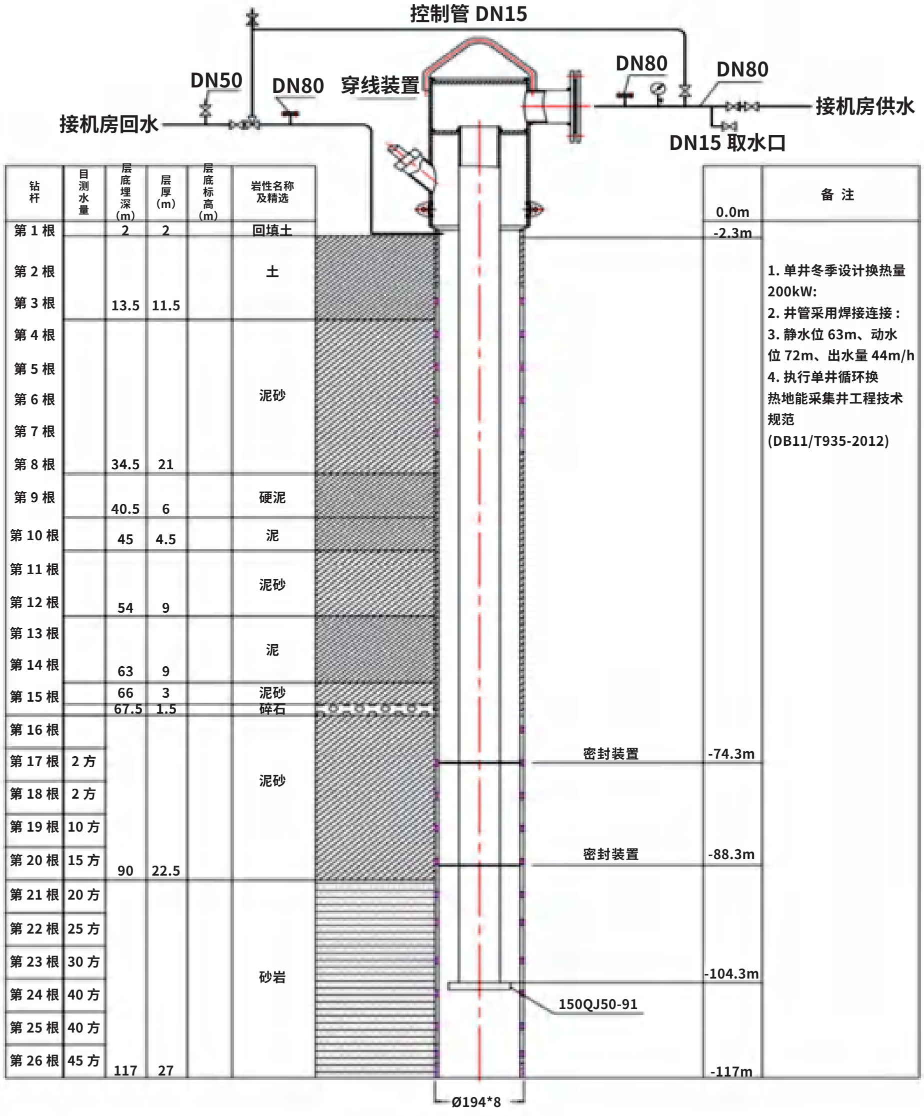


图 4 采集井装置图

4. 运行及节能减排效果

4.1 运行能耗统计

表 3 2021–2022 年供暖季能耗数据统计表

<table>
<tr><th>序号</th><th>建筑物名称</th><th>面积（㎡）</th><th>冷热源站系统</th><th>年采暖耗电量（万kW*h）</th><th>年平米采暖耗电量（kW*h/㎡）</th><th>电价（元kW*h/）(2021 年)</th><th>年采暖费用（万元）</th><th>年平米采暖费用（元 / ㎡）</th></tr>
<tr><td>1</td><td>1# 小学部</td><td>19732</td><td>1# 站</td><td>47.85</td><td>24.25</td><td>0.4721</td><td>22.59</td><td>11.45</td></tr>
<tr><td>2</td><td>2# 中学部</td><td rowspan="2">27205</td><td rowspan="2">2# 站</td><td rowspan="2">50.66</td><td rowspan="2">18.62</td><td rowspan="2">0.4721</td><td rowspan="2">23.92</td><td rowspan="2">8.79</td></tr>
<tr><td>3</td><td>3# 海外剧场</td></tr>
<tr><td>4</td><td>4# 综合体育中心</td><td rowspan="2">7797</td><td rowspan="2">3# 站</td><td rowspan="2">18.02</td><td rowspan="2">23.11</td><td rowspan="2">0.4721</td><td rowspan="2">8.51</td><td rowspan="2">10.91</td></tr>
<tr><td>5</td><td>滑雪厅</td></tr>
<tr><td>6</td><td>5# 冰雪中心</td><td>4558</td><td>4# 站</td><td>6.96</td><td>15.27</td><td>0.4721</td><td>3.29</td><td>7.21</td></tr>
<tr><td>7</td><td>6# 国际部高中</td><td>30456</td><td>5# 站</td><td>51.02</td><td>16.75</td><td>0.4721</td><td>24.08</td><td>7.91</td></tr>
<tr><td>8</td><td>7# 国际部初中</td><td>29849</td><td>6# 站</td><td>45.55</td><td>15.26</td><td>0.4721</td><td>21.51</td><td>7.20</td></tr>
<tr><td>9</td><td>8# 幼儿园</td><td rowspan="2">17818</td><td rowspan="2">7# 站</td><td rowspan="2">38.98</td><td rowspan="2">21.87</td><td rowspan="2">0.4721</td><td rowspan="2">18.40</td><td rowspan="2">10.33</td></tr>
<tr><td>10</td><td>11# 后勤办公楼</td></tr>
<tr><td>11</td><td>合计</td><td>137416</td><td></td><td>259.03</td><td>19.30</td><td></td><td>122.29</td><td>9.11</td></tr>
</table>

4.2 项目一、二期与三期运行能耗对比

表 4 海淀外国语实验学校一二期与三期项目地能热泵环境系统运行数据对比

海淀外国语实验学校一期二期与三期 (京北校区) 地能热泵环境系统运行数据对比表			
序号	对比内容	一二期 (海淀校区)	三期 (京北校区)
1	建筑面积	100000 ㎡	137416 ㎡
2	供暖开始时间	10 月 25 日	10 月 15 日
3	供暖结束时间	4 月 2 日	3 月 31 日
4	制冷开始时间	5 月 18 日	6 月 8 日
5	制冷结束时间	9 月 20 日	9 月 15 日
6	供暖季采集井供水温度	16.5°C	15°C

海淀外国语实验学校一期二期与三期（京北校区）地能热泵环境系统运行数据对比表			
序号	对比内容	一二期（海淀校区）	三期（京北校区）
7	供暖季采集井回水温度	13.5°C	10°C
8	供暖季末端供水温度	42.2°C	42°C
9	供暖季末端回水温度	37.9°C	38°C
10	供暖季总能耗	3792000kW.h	2590300kW.h
11	供暖季每平米能耗	37.92kW.h	19.30kW.h
12	制冷季采集井供水温度	28°C	20°C
13	制冷季采集井回水温度	30.3°C	24°C
14	制冷季末端供水温度	13.8°C	12°C
15	制冷季末端回水温度	15.4°C	15°C
16	制冷季总能耗	1474000kW.h	847900kW.h
17	制冷季每平米能耗	14.74kW.h	6.17kW.h
18	全年总能耗	5266000kW.h	3438200kW.h
19	全年平均每平米能耗	52.66kW.h	25.02kW.h

海淀外国语实验学校项目三期京北校区与一期二期校区对比，采集井系统以及一次、二次管网设计更加科学合理，全年每平方米能耗降低约 52.49%。

4.3 节能及减排成果

项目供暖季总能耗为 259.03 万 kW.h 电能，折合 318t 标煤。与采用电直热式供暖比较，可节能约 800t 标煤，可再生能源利用率达 60%, 每年可减少 CO_2 排放 1976t，减少 SO_2 排放 16t，减少粉尘排放 8t。

5. 主要技术进步和创新

20 年的时间里，单井循环换热浅层地热能供暖技术获得以下发展和创新：

1）发明了有换热颗粒采集井，井水由置于隔热管底部抽水区的潜水泵抽出，进入热泵机组放热或吸热后，由热泵机组返回进入地能采集井的上部加压回水区内。水流在有换热颗粒的环形空间内向下流动至抽水区，透过隔热管下部的花管部分进入隔热管，再由潜水泵抽出 [2]。围绕井管周围置入换热颗粒，局部地改善地质环境，扩大高效率换热的范围（图 5），换热颗粒宜采用直径 10mm-100mm 的球形体，强度大于 50 兆帕 [2]。

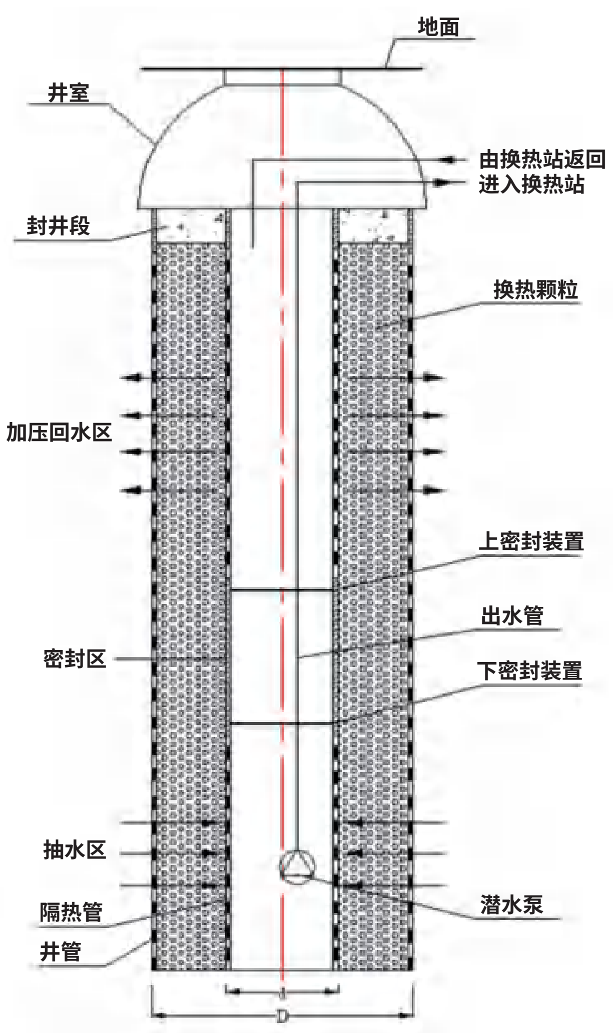


图 5 有换热颗粒地能采集井结构图

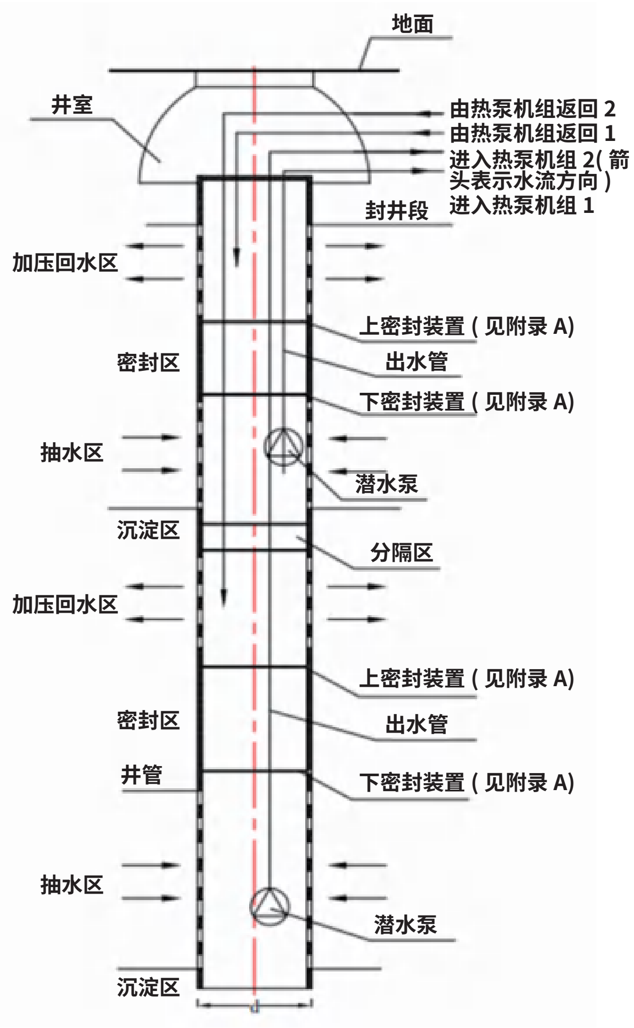


图 6 多含水层地质结构地能采集井

2）针对在多含水层地质结构中串层抽水的问题，研发了多水层无换热颗粒地能采集井技术，采用两个或多个井上下叠加及密封的结构，实现了多含水层地质结构的同层回灌（图 6）。

3）2012 年恒有源科技发展集团有限公司编制了《单井循环换热地能采集井工程技术规范》DB11/T 935-2012，为单井循环换热地能采集井的设计、施工提供了规范。

6. 其他工程案例

单井循环换热地能采集技术自 2001 年在北京推出以来很受用户认可并迅速推广。现在已经推广至中国除港澳台、海南等省外全境和地区，计 800 多个项目，总建筑面积超过 2000 万㎡，建筑类型包括：政府办公楼、商业写字楼、住宅楼、大型商场、体育馆、档案馆、医院、学校、工业厂房、景

观水池等。表 5 是部分在北京及周边主要的工程实例。

7. 结论

浅层地热能是太阳能和地心热共同作用的产物，是清洁的可再生的能源，温度在 25°C以下。借助热泵技术改变它的热能的品位，冬天可以用来采暖，夏天可以制冷。在建筑领域作为供暖 / 冷的替代能源很有开发利用价值。

单井循环换热地能采集技术是一项我国原创的，先进的，适用于多种地质条件的浅层地能采集技术。它以循环水为介质采集浅层地下的热能，可以实现地下水同层就地全部回灌，不消耗也不污染地下水，对地下水是安全的。现在这种技术已走出国门，在美国等国外示范工程也已投入运行。

北京市海淀外国语实验学校京北校区是采用单井循环换热地能采集技术的新近案例，与二十年以前相比系统更加可靠安全。系统能效比提高了，节能减排效果进一步增强。可以期望单井循环换热地能采集技术助力开发利用浅层地热能进一步发挥优势，为早日实现双碳目标做出贡献。

表 5 工程案例表

序号	名称	用途	建筑面积 (m^2)	地址	备注
1	全国工商联办公楼	办公楼	50000	北京市西城区德胜门西大街	单体建筑
2	海淀外国语实验学校	学校	62851	北京市海淀区	
3	国家行政学院港澳中心	办公楼	43000	北京市海淀区	
4	金四季购物中心	商业	116000	北京市淀区西北四环	单体建筑
5	雄安市民服务中心	办公楼	99600	河北省雄安新区	
6	国家大剧院	景观	30000	人民大会堂西侧	景观水池温控
7	海淀区农村应用项目	住宅	800000	北京市海淀区	

参考文献

[1] 徐生恒 ,Rybach. 浅层地能资源的利用 – 单井抽灌技术的实例研究 [J]. 地热资源委员会，2003 年会会议论文集

[2] 北京市地方标准 . 单井循环换热地能采集井工程技术规范 [S]. 北京 ：北京市质量技术监督局，2011 年 12 月，编号 ：DB11/T 935–2012

[3] 武强 , 徐生恒 . 基于单井循环浅层地热能开发的数值模拟与分析 [J]. 工程勘察，2015 ，(1)：45–50

浅层地热能 + 太阳能发电多能互补分户式供暖（冷）技术方案和案例研究

——2023 年世界地热大会入选论文

SHALLOW GEOTHERMAL ENERGY + SOLAR POWER MULTI-ENERGY COMPLEMENTARY HOUSEHOLD HEATING (COOLING) TECHNICAL SOLUTIONS AND CASE STUDIES

—— Paper presented at the 2023 World Geothermal Congress

作者：刘宝红、李艳超、史永亮、杨明忠、李松、王学志、关秀虎、徐生恒

摘　要：利用浅层地热能为农村建筑提供分户供暖热源，采用屋顶太阳能发电与市政电多能互补的方式为热泵系统提供驱动电源，可以实现环境效益和经济效益的优化。本文以北京冬奥会的张家口赛区义合堡村的实际项目为例，介绍了以浅层地热能 + 太阳能发电多能互补为农村建筑分户供暖（冷）的应用情况和实际效益。至 2022 年，该项目已稳定运行 6 年，采用单井循环换热技术就近采集浅层地热能，集中地热能交换和输送，分户供暖，分间配置可调节的热泵设备，成功地解决了农村家庭供暖高能耗、热舒适性差、分房间控制难度大、配电网容量低等农村家庭清洁供暖普遍存在的问题，实现了区域采暖零碳排放。文末提出了新一代低压直流供电驱动的多能耦合分户式供暖（冷）系统方案，可实现农村建筑物的零碳供热（冷）。

关键词：浅层地热能；单井循环换热；太阳能发电；多能互补；分户供暖（冷）

引 言

中国北方农村人口众多地域广阔，属于严寒或寒冷地区。历史的原因造成农村建筑维护结构的保温性能差，层高较高，建筑面积普遍较大，为城市居住建筑供暖能耗的 1.5-2 倍 [1]。农村住宅需要“部分时间、部分空间”采暖模式 [2]。另一方面农村供电容量有限，难以实现常规的电采暖等电替煤供暖改造。农村家庭需要配电容量低、分间控制灵活、高效节能、环保又经济的供暖（冷）系统。

本文提出以浅层地热能作为北方农村建筑供暖的替代能源，耦合太阳能发电驱动热泵的农村分户供暖（冷）方案，尝试解决北方农村家庭清洁供暖（冷）的瓶颈问题。

1. 技术方案

1.1 浅层地热能分户式供暖（冷）系统

浅层地热能分布广，蕴藏量丰富，采用单井循环换热技术大面积的开发利用这一能源为建筑物供暖、供冷和制取生活热水，有很好的节能环保效果 [3]。采用单井循环换热集中采集浅层地热能的分户供暖（冷）系统简称单井循环换热地能热宝系统，利用集中地能换热站，通过地能输送管网将温度≤ 25°C的热源水输送到各户，户内设地能热宝设备（户内末端为热泵热风机），系统示意如图 1。

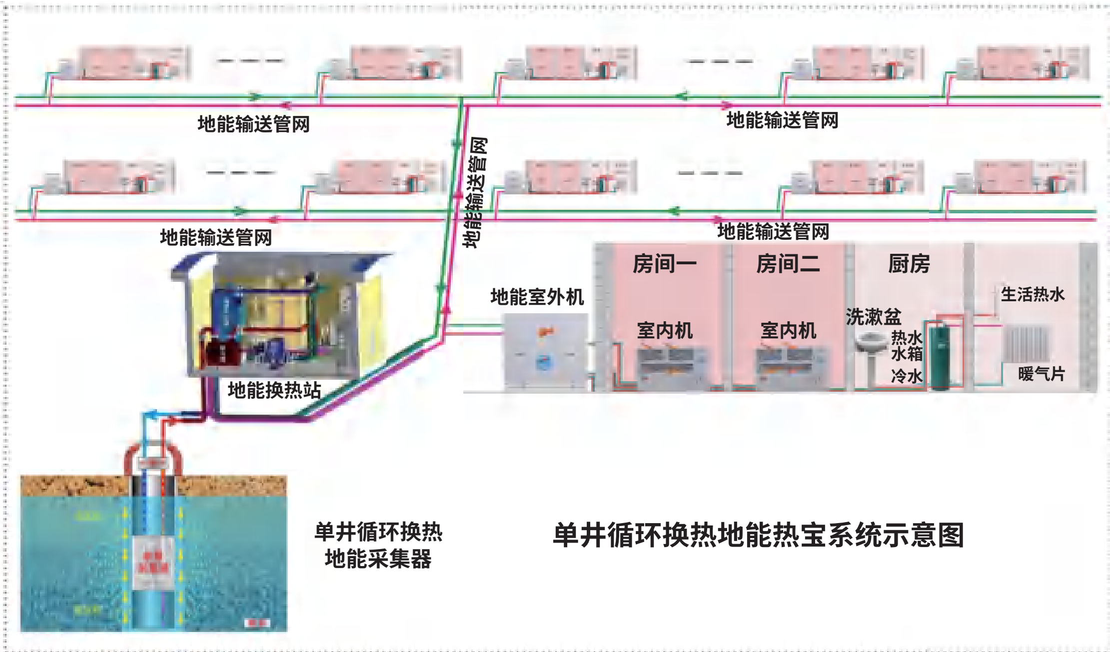


图 1 单井循环换热地热能户用供暖系统原理图

系统兼有普通家用分体空调的控制灵活、操作简便等优点，可实现分户电计量、分间控制地为家庭供暖（冷），配电容量低于普通分体空调。单井循环换热地能热宝系统与普通地源热泵系统的差异如表 1。

表 1 单井循环换热地热能户用供暖系统与普通地源热泵系统的区别

系统形式	地热能交换系统	地能侧输配系统	热泵机组	用户侧散热（冷）介质	末端装置	特点
普通地源热泵系统集中供暖	集中采集地热能	集中设置	集中设置	热（冷）水	散热器；辐射地板；风机盘管；	①可考虑同时使用系数，降低装机容量；②热源温度不低于 35℃，输配管网热损大；③大锅饭制，无法满足个户差异需求。
普通地源热泵系统分户供暖	分户采集地热能	分户设置	分户设置	热（冷）水	散热器；辐射地板；风机盘管；	①个体独立，满足差异化需求；②适合采用地埋管地热能采集系统，钻孔占地面积大，建设成本受地质条件影响较大；③整体供暖，难以实现分间控制。
单井循环换热地能热宝系统	集中采集地热能	集中设置	分户设置，分间配	热（冷）气	热泵热风机	①地热能采集可考虑同时使用系数，降低建设成本；②地能输配系统为低温热源（≤ 25℃）输送，热损少；③能实现分户计量，分间控制，行为节能；④每户 2kW-3kW 配电量，普通分体空调配电就能满足电容量要求。

1.2 系统的创新

1.2.1 分房间配置的热泵热风机

地能热宝设备的室内机为热泵热风机，分间配置可调节，按需启停，温度可在 16-32℃区间控制。室内机不开也不会冻坏，可以人在哪屋开哪屋设备，不在不开，方便行为节能，避免整体供暖产生不必要的浪费。地能热宝设备为变频控制，根据室内机开启数量和室内外温度调整热泵机组工作频率，高效节能。

1.2.2 适合农村建筑供暖的卧式结构散热设计

地能热宝的室内机为卧式结构，落地安装或是距地面 0.2-0.3m 壁挂安装，运行主要以下出风口为主，针对人体活动区域上出口可以灵活调节出风角度，在人体活动区域高度定向送暖风供热，让活动区域快速升温。特殊的下出风口送风可贴地面流动、扩散，随着热风逐渐自然上升，整个房间温度均匀升高，达到地暖供热的舒适度，并且升温速度快，如图 2。

卧式结构室内机供暖房间在人活动的高度区域温度相对较高，房间屋顶及四周温度要低 3-7℃，比房屋各面温度一样时的供暖能耗要节省 15% 左右。卧式结构散热使房间温度有地板辐射采暖的“暖足凉顶”效果，提高

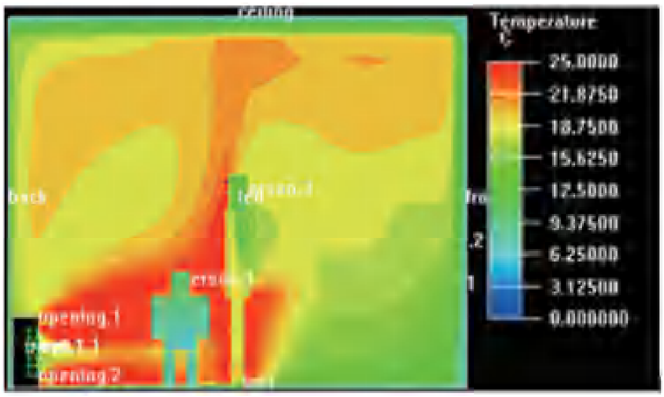


图 2 卧式结构供暖房间温度场

了房间温度和舒适感，解决了农村建筑因空间大带来的供暖能耗大和温度低的问题。

1.2.3 多能互补可创收

太阳能发电系统的运行模式为“自发自用，余电上网”。在过渡季节，太阳能发电量优先应用于家庭电器用电，多余电量上网。在供暖（冷）时期，太阳能发电量优先应用于地能热宝设备，当太阳能发电量大于地能热宝设备的耗电量，地能热宝系统和家庭电器用电所需电量全部由太阳能发电提供，且剩余电量全部上网；当太阳能发电量小于地能热宝设备的耗电量时，太阳能发电量全部用于地能热宝系统，不足部分由市政电网提供；系统多能互补提供电能驱动地能热宝设备工作。系统供暖的热量都来自于低品位的浅层地热能，热泵只消耗了少量的电能起了搬运的作用[4]。

地能热宝系统供暖和制冷的电耗都少，与太阳能发电耦合能产生较多的剩余绿电上网，带来经济效益，很好地解决农村建筑供暖（冷）的需求和创收问题。

2. 案例应用数据

义和堡村位于奥运廊道张家口市怀来县，全年平均气温 5.5-6.5℃，冬季供暖设计温度 -13.6℃，属寒冷 A 区。太阳能年总辐射量 5700-6100 MJ/ ㎡，属第二类资源区。

2.1 方案配置

义和堡村建筑均为单层建筑，外墙为 370mm 红砖墙，无保温，门窗为单层木质或单层铝合金材料。每户东西长 13.2m，南北长 7.8m，供暖面积约 100 ㎡。按冬季 18℃、夏季 26℃计算，全年供暖热负荷 10478kWh，全年制冷冷负荷 3323kWh。

整村共计 265 户，分东、西两个区域。每户地能热宝设备为 1 套一拖二（制热量 7.6kW，输入功率 1.9kW）和 1 套一拖一（制热量 3.7kW，输入功率 0.9kW），每户太阳能发电采用 20 块 265Wp 光伏组件，总功率 5.30kWp。多能互补供电系统采用 1 台 5kW 光伏逆变器，接入 220V 线路送入家庭原有室内进户配电箱，再经由 220V 线路与室内低压配电网进行连接。浅层地热能 + 太阳能发电多能互补分户供暖（冷）系统配置如表 2。

2.2 应用数据

公司在 2022 年 6 月对项目进行了实地调研回访，反馈 236 户数据，同时整理 6 年的系统应用数据。应用数据主要有三类，第一类为改造前燃煤炉烧煤量、室内温度；第二类为改造后的供暖（冷）耗电量、室内温度、室内散热设备开机时间、日常生活用电量；第三类为太阳能发电量、实际收益。

表 2 配置浅层地热能 + 太阳能发电多能互补的家庭采暖 (冷) 系统

分区	户数(户)	地能换热站				地能热宝设备		太阳能发电功率（kWp）
		单井数量（个）	潜水泵功率（kW）	换热站循环泵功率（kW）	总功率（kW）	一拖一数量（台）	一拖二数量（台）	
东区	223	5	55.2	18.5	64.5	223	223	1181.9
西区	42	1	9.2	3	12.2	42	42	222.6

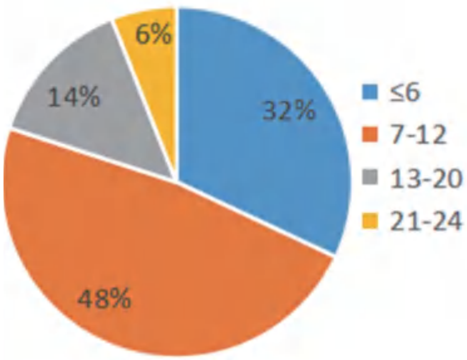


图 3 室内机开机时间饼图

2.2.1 改造前后供暖对比

改造前农户各家烧燃煤炉取暖，每天人工添加煤块和清除煤渣。每户一个采暖季烧散煤 2.5-3.5t（散煤热值取 5000kcal/kg），折合标煤 1.79-2.5t。有 75% 的家庭供暖房间温度≤ 16℃，房间温度随加煤频率变化大，供暖温度不稳定。改造后农户遥控器控制室内机启停，操作方便。冬季供暖耗电量 2200-3190kWh，有 80% 的用户反馈供暖房间室温 18℃左右，有 20% 的用户反馈温度在 20℃以上，同时地能热宝系统夏季可以制冷。用户普遍认为使用舒服和方便。

2.2.2 室内机使用情况

经过实地调研应用情况，多数农户使用模式为白天用哪间房开哪间房和晚上卧室连续开机运行，室内机开机时间饼图如图 3。可以看出，每天运行≤ 6h 和 7h-12h 的室内机占比分别为 32% 和 48%，连续运行 21h 及以上的室内机数量占比为 6%，连续开机运行的用户为有幼儿或患病老人的家庭。分房间调节型的室内机符合“部分时间、部分空间”的采暖模式，最大限度地满足农村家庭“省着用”的习惯，行为节能降低能耗。

2.2.3 家庭每年经济收益

至 2022 年，项目已稳定运行 6 年，地热能系统总耗电 600.7 万 kWh，太阳能发电量共计 1236.04 万 kWh，太阳能发电除用户自用外，共计上网电量 1026.23 万 kWh。

义和堡村张氏家庭 2020 年 8 月 1 日 -2021 年 7 月 31 日的多能互补系统收益如表 3。全年发电量 8183kWh、上网电量 6794kWh、家庭日常用电量 1948kWh、地能热

表 3 多能互补系统的好处

	过渡季（03.16-06.14、09.16-11.14）		供暖季（11.15-03.15）		制冷季（06.15-09.15）		全年
	市政电	太阳能发电	市政电	太阳能发电	市政电	太阳能发电	
太阳能发电（kWh）		3391.5		2439		2352.5	8183
太阳能上网电（kWh）		3319.5		1637		1998.5	6955
家用电器耗电（kWh）	786	72	550	40	470	30	1948
冬季制热耗电（kWh）			1820	762			2582
夏季制冷耗电（kWh）					168	324	492
换热站公摊电（kWh）			608.6		350		958.6
上网电收益（元）		3292.9		1623.9		1982.5	6899.4
市政电费（元）	-408.7		-1548.9		-513.8		-2471
总收益（元）	2884.2		75.0		1468.8		4428.0

注：①上网电价为 0.992 元 /kWh（国家补助 0.42 元 /kWh、省补助 0.2 元 /kWh、基础电价 0.372 元 /kWh）；市政电价为 0.52 元 /kWh；
②家庭电器主要包含照明、电视、冰箱、洗衣机、电热水壶等；

宝系统全年耗电量 4197.6kWh。太阳能发电上网收益 6739.6 元、市政电费 2473 元、家庭总收益 4266.2 元。

3. 适用性分析

3.1 经济性分析

农村电代煤实施过程中，由于居民对供暖方式的不同选择，系统设备的寿命和维护费用均不同。利用费用年值法来计算各个系统的经济性，系统费用年值 Y 的公式为：

$$Y = C\frac{i(1+i)^n}{(1+i)^n - 1} + F$$

式中：Y——系统的费用年值，元 /a；

C——系统的造价，元；

i——银行利率，取 0.0465；

n——系统的使用寿命，a（年）；

F——系统年运行费用，包括电费与维护管理费用，元 /a；

在满足农村家庭冬季采暖、夏季制冷需求的前提下，将地能热宝、户用低温空气能热泵热风机（户内末端为热泵热风机）分别与太阳能发电组成 2 种耦合系统，对其经济性进行分析，具体如表 4。

地能热宝 + 太阳能发电系统费用年值为 1252 元 / 年，空气能热泵热风机 + 太阳能发电系统费用年值为 2793 元 / 年，推广地热能 + 太阳能发电多能互补系统具有更大的经济效益。

表 4

供暖系统	地热能（地能热宝）+ 太阳能发电	空气能（热泵热风机）+ 太阳能发电
热泵设备造价（元）	28981	18000
太阳能发电设备（元）	33962	33962
使用寿命（年）	20	15
年电费（元）	-4428	-2614.2
维护管理费用（元）	629.43	519.62
费用年值（元）	1103	2793

备注：

①义和堡村浅层地热能分户供暖（冷）系统投资 768 万，太阳能发电系统投资 900 万元；

②根据表 3 数据可知，张氏家庭地能热宝系统冬季供暖耗能 3190.6kWh，夏季制冷耗能 842kWh，均包含地能换热站公摊电量；耦合系统总收益 4428 元

③空气能热泵热泵热风机设备造价 6000 元 / 套 [5]，空气能热泵热泵热风机耗能 55.3kWh/ ㎡ · 采暖季 [6]，一个家庭冬季供暖耗能 5530kWh；制冷系数按取 3.5 计算，制冷电耗 950kWh；根据表 3 数据计算，耦合系统年总收益为 2614.2 元；

④维护管理费用取系统总投资的 1% 估算。

3.2 环境效益分析

环境效益主要有两部分来源，一部分为地能热宝系统替代燃烧散煤供暖带来的零污染、零排放环境效益，一部分为太阳能发电替代火电厂生产和输送带来的环境效益。散煤减排根据《民用煤大气污染物排放清单编制技术指南》[7] 计算，太阳能发电产生的环境效益根据中国电力行业年度发展报告（2017）[8] 和《可再生能源建筑应用工程评价标准》[9] 计算数据，每年的节能减排量如表 5。

表 5 全年节能减排

	节煤量（tce）	二氧化碳排放量 (t)	二氧化硫排放量 (t)	烟尘排放量 (t)
减少散煤 795 吨	567.85	2082.90	5.88	8.24
结余绿电 132.2 万 kwh	412.46	1018.79	8.25	4.12
汇总	980.46	3101.69	14.13	12.36

注：
①根据《民用煤大气污染物排放清单编制技术指南（试行）》，二氧化硫、颗粒物的排放标准分别为：7.4kg/t 散煤（排放系数取 7.4St,d, 其中 St,d 取 1）、10.36kg/t 散煤（烟煤干燥无灰基挥发分 Vdaf 取 37%，则烟尘排放系数为 0.28Vdaf=10.36），二氧化碳排放按 2.62t/t 散煤计算；
② 2016 年，全国 6000 千瓦及以上火电厂供电标准煤耗 312 克 / 千瓦时。

改造前整村每年燃烧散煤 567.9t 标煤，地能热宝系统每年供暖消耗电能 84.6 万 kWh，太阳能每年发电 216.8 万 kWh，结余绿电 132.2 万 kWh。每年可减少二氧化碳排放 3101.69t、减少二氧化硫排放 14.13t、减少烟尘排放 12.36t，具有较好的环境效益。

4. 新一代直流供电耦合蓄能分户供暖（冷）系统

清华大学的刘晓华等人研究发现，大多数乡村建筑可利用自身的太阳能光伏资源，有效解决其自身能源需求，并且多余电力上网，使得乡村具有显著太阳能光伏利用潜力，有望成为未来零碳电力系统中重要的分布式电力来源[10]。采用浅层地热能直流供电产品 + 屋顶太阳能发电 + 蓄能调节多能耦合系统可实现家庭零碳供暖（冷）和全年绿电。

我公司正在研究新一代直流供电驱动的浅层地热能分户供暖（冷）产品，采用 48V 低压全直流技术，直接与太阳能发电供能结合。3 匹一拖三地能热宝机组能效比 5.5，制热量 7500W、制热功率 1500W；制冷量 8200W、制冷功率 1360W；可作为地热能直流供暖（冷）产品的发展参考。

新一代低压直流供电驱动的多能耦合分户式供暖（冷）系统示意图如图 4。系统由直流供电驱动的地能热宝系统、蓄能系统、太阳能发电设备、控制器、逆变器等电路配套元件组成。冬季供暖，地能热宝系统消耗 1 份直流电能驱动变频压缩机、循环水泵等元器件工作，吸收 4 份浅层地热能，供给建筑 5 份

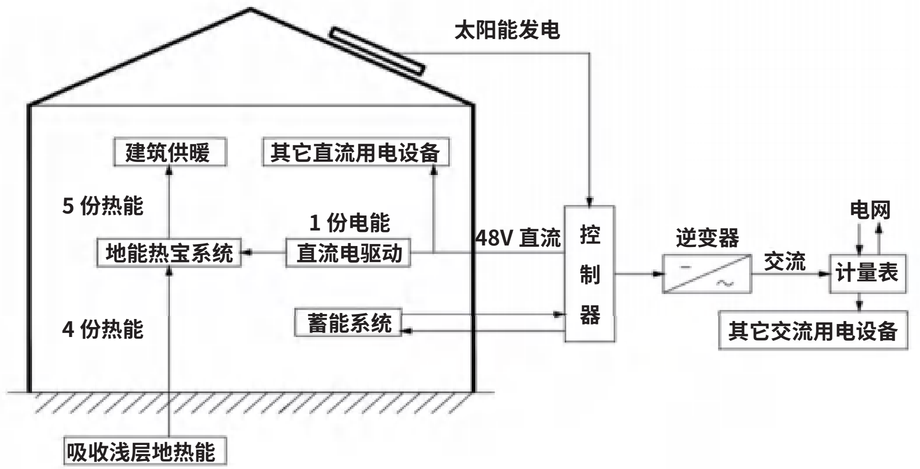


图 4 多能耦合家用热（冷）系统原理图

热能采暖。夏季将地能热宝机组里的四通阀换向，能给建筑制冷。蓄能系统能存储多余的电能，在晚上或阴雨天气释放出来驱动地能热宝系统工作，也能经逆变器转换电压后并电网产生经济收益。

系统使用能源来自于地下浅层地热能和太阳能，绿色节能；直流供电无需二次转换，太阳能发电量利用率更高；蓄能系统让多余电量自动安全存储，提高自用的比例；因电网单价比上网电价高，系统又能产生更多的经济效益。

5. 结论

义和堡村的浅层地热能 + 太阳能发电多能互补分户式供暖（冷）系统，利用浅层地热能为农村建筑分户供暖（冷），采用分房间调节和卧式结构的地能热宝设备，具有配电量小、操作简单、分间控制、温度舒适、高效节能等特点，解决了农村建筑供暖存在的问题；同时结合屋顶太阳能发电，每年能给农户增加经济收入；系统具有地热能 + 多能互补的创新性和实践意义。

未来随着直流供电产品的上市，浅层地热能供暖（冷）+ 屋顶太阳能发电 + 蓄能调节系统能实现家庭零碳供暖（冷）和全年绿电，是农村家庭一种优化供能策略，协调了资源、经济与环境的关系，是符合“双碳”发展要求的农村建筑新能源系统。

参考文献

[1] 刘晶，邹瑜，宋波，严寒和寒冷地区农村居住建筑现状调研与节能途径 [J]，建筑科学，2012 年第 012 期：1-5；

[2] Rongjiang Ma，Chunliu Mao，Ming Shan，etal.Occupant control patterns of low temperature air-to-air heat pumps in Chinese rural households based on field measurements [J].Energy and Buildings，2017，154：157-165；

[3] 徐生恒，Ryach，浅层地能资源的利用 - 单井抽灌技术的实例研究 [J]，Geothermal Resources Council 2003 Annual Meeting；

[4] 吴德绳，用低品位能源为建筑物供暖是高尚的追求 [J]. 中国地能，2015 年第 8 期：30-33；

[5] 淄博冬季清洁取暖电采暖设备空气源热泵热风机供应商 https://www.doc88.com/p-4827396494738.html?s=rel&id=8；

[6] 郭威炯，黄必鹤，张继皇，河北农村地区清洁取暖“煤改电”技术可行性试验分析 [J]，电力需求侧管理，2019,21（02）：46-50；

[7] 民用煤大气污染物排放清单编制技术指南（试行）；

[8] 中国电力行业年度发展报告（2017）；

[9] 可再生能源建筑应用工程评价标准，GB/T 50801-2013:24-26；

[10] 刘晓华，张涛，刘效辰，江亿，“光储直柔”建筑新型能源系统发展现状与研究展望 [J/OL]，暖通空调，2022；
https://kns.cnki.net/kcms/detail/11.2832.TU.20220516.1224.002.html

再探青藏高原十大关键地学科学问题

——《地质学报》百年华诞纪念

REVISITING THE TEN KEY GEOSCIENTIFIC PROBLEMS IN THE QINGHAI-TIBET PLATEAU

——《ACTA GEOLOGICA SINICA》100th Anniversary

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内容提要：本文重新审视了青藏高原的关键科学问题，为解决板块构造理论的“登陆”难题提供新的线索，为理解板块汇聚边界的大陆岩石圈演化及其能源资源、地质灾害和全球环境效应提供新的思路。本文探讨了青藏高原如下十大关键地学问题：① 印度大陆北漂模型；② 印度 - 亚洲初始碰撞时限；③ 青藏高原的古特提斯造山作用；④ 古近纪喜马拉雅造山带的地壳缩短；⑤ 高喜马拉雅的深熔机制；⑥ 青藏高原隆升的时限和差异性；⑦ 构造 - 剥蚀 - 气候相互作用与南亚季风；⑧ 青藏高原关键矿产资源的分布与成因；⑨ 青藏高原的活动断裂带与孕震机制；⑩ 碰撞后的印度板块何去何从—深部动力学过程。这些问题可以作为当前研究青藏高原大陆动力学演化的重点方向。

关键词：青藏高原；板块构造；大陆动力学

青藏高原是世界上最高、最大、最厚、最新的高原，是发展固体地球科学理论的最佳实验室。青藏高原研究从喜马拉雅开始已经有 200 多年的历史，重新审视和探究青藏高原的关键科学问题，可以为研究板块汇聚边界的大陆岩石圈演化及其能源资源、地质灾害和全球环境效应提供新的重要信息，为解决板块构造理论的“登陆”难题做出贡献。

印度 - 亚洲碰撞是新生代以来最壮观的地质事件，导致喜马拉雅山脉的崛起、青藏高原的隆升、巨厚地壳的形成、青藏高原物质向东、东南和向西南的大逃逸、2000km 范围亚洲大陆内部的弥散变形、环青藏高原的盆地系统和油气资源、南亚季风和亚洲内陆干旱化等。笔者提出青藏高原如下重大关键地学问题，作为研究青藏高原的新思考：① 印度大陆北漂模型；② 印度 - 亚洲初始碰撞时限；③ 青藏高原的古特提斯造山作用；④ 古近纪喜马拉雅造山带的地壳缩短；⑤ 高喜马拉雅的深熔机制；⑥ 青藏高原隆升的时限和差异性；⑦ 构造 - 剥蚀 - 气候相互作用与南亚季风；⑧ 青藏高原关键矿产资源的分布与成因；⑨ 青藏高原的活动断裂带与孕震机制；⑩ 碰撞后的印度俯冲板块何去何从——深部动力学过程。以此作为对《地质学报》100 周年华诞的纪念。

7. 构造 - 剥蚀 - 气候相互作用与南亚季风

人们已经认识到固体地球的构造演化对于大气和海洋具有重要的影响。山脉的隆升、大洋和盆地的开合控制了全球范围的水和大气的循环，反过来又影响区域的气候和剥蚀速率 (Molnar et al.,1993,2010)。

因此，抬升的高原和山脉可以扰乱大气环流 (Manabe et al.,1974), 而由于剥蚀和沉积物的转移与气候变化密切相关，降雨模式的变化对造山带构造的时限和几何学有重要的影响，并会促进深部岩石的折返 (Beaumont et al.,2001;Sinclair et al.,2005;Wobus et al.,2005)。

同样，大洋的开合可以将暖流转移到高纬度地区，在超过百万年或更大的时间尺度内影响区域或全球的气候变化，亚洲季风系统被认为是最引人注目的例子。

南亚季风是指亚洲南部的季风（以印度半岛为典型），又称“印度季风”。一般认为其形成原因受地球风带的季节性移动、海 - 陆热力差异和地形因素的影响。青藏高原和喜马拉雅地形隆升、北半球或全球气候变化和印度季风的起因已成为重要的科学问题 (An Zhisheng et al.,2001;Beaumont et al.,2001)。然而，气候与板块俯冲动力学如何相互影响？又是谁先谁后？“鸡和蛋”的挑战限制了我们对“气候 - 侵蚀 - 构造”相互作用的理解。

人们早已认识到在碰撞环境下的喜马拉雅造山过程中存在大量逆冲断裂体系，然而，理解喜马拉雅中应力调节的最大贡献应该是藏南拆离系 (STD) 的发现 (Burchfield et al.,1992)。因此，高喜马拉雅角闪岩相岩石的折返被认为是在喜马拉雅造山带南麓降水导致的地表快速剥蚀影响下，藏南拆离系和主中央逆冲断层夹持的地壳隧道流在约 23~17Ma 向南挤出的结果 (图 14)(Beaumont et al.,2001), 这一模式受到广泛关注 (Searle et al., 2005;Godinetal.,2006;Hodge,2006)。

20 世纪 90 年代早期，人们试图将印度 - 亚

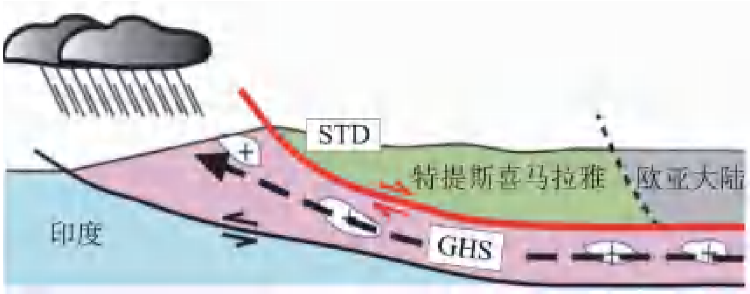

图 14 高喜马拉雅中地壳隧道流模式

GHS—高喜马拉雅岩系；STD—藏南拆离系

洲碰撞构造演化和约 8Ma 左右的季风强度联接起来 (Kroon et al.,1991;Prell et al.,1992)。但是大量研究表明，强季风的发生时间要比原来的认识早的多，可能从始新世开始，在中新世早期—中期加剧，随后中新世中期到晚期（约 12~8Ma) 气候干燥，并不是季风强降雨期 (Clift et al.,2018)。

Clift et al.(2018) 认为南亚季风是喜马拉雅屏障效应的产物，为解释早—中中新世的夏季强降雨的原因提供了新机制。高喜马拉雅中地壳物质的快速折返基本上与中新世早期—中期的气候变化引发的强季风期是同期的，这意味着该阶段的地表剥蚀速率加快，促进了深部物质的折返。

但是最近人们认识到，沿着喜马拉雅的走向，高压变质岩的折返时限与相伴随的构造运动是同时的。Webb et al.(2017) 统计了前人对喜马拉雅造山带岩浆活动、变质作用和年代学的研究成果，发现整个高喜马拉雅在 26~2Ma 都经历了从进变质作用到退变质作用的转变，沿造山带走向，藏南拆离系的活动停止时间是东、西构造结较早（约 24~20Ma), 而中部偏晚（约 13~11Ma)。这种趋势可能受俯冲板片动力学控制，印度板块的俯冲角度在 30~25Ma 变陡，导致板片断离从边部向中部扩展，构造抬升沿走向变化，造成喜马拉雅弧形山系以及南亚季风的加强（图 15)。因此，青藏高原和喜马拉雅的抬升时间及其时空变化对理解构造 - 剥蚀 - 地貌的耦合过程至关重要。

Clift et al.(2018) 回顾了南亚季风的历史，推测 24Ma 时为强烈降雨期，15Ma 为峰值湿润期，8Ma 为干燥期。这些年龄段恰与青藏高原 - 喜马拉雅的隆升和海水退出有关。特别是中新世的喜马拉雅快速隆升对北上的夏季季风和降雨提供了一个突然的地貌屏障，使自西向东的气流发生偏转，这种情况可能一直持续到今天 (Molnar et al.,2010)。

8. 青藏高原关键性矿产资源的分布与成因

锂 - 铍 - 钽稀有金属已经成为重要的战略性关键矿产资源，是发展新能源产业、保障和社会经济持续发展的关键矿种之一。近年来，随着锂电池、新能源汽车、可控核聚变等领域快速发展和不断突破，锂的战略地位不断提升，被誉为“21 世纪的能源金属”。由特提斯域地体拼贴体组成的青藏高原是中国大陆关键性矿产资源的重要集结地，其中，稀有金属成矿潜力成为目前青藏高原资源响应中最薄弱部分。在实施“新能源矿产资源战略”的今天，松潘 - 甘孜造山带甲基卡、马尔康和白龙山等大型—超大型锂矿床的发现引起国内外同行高度重视，使松潘 - 甘孜造山带有可能成为一个伴生 Be、Nb、Ta、Sn、Rb 和 Cs 元素的超常锂元素富集地带（图 16; 许志琴等，2015b,2018; 付小方等，2017;Xu Zhiqin et al.,2020)。

位于青藏高原中北部的松潘甘孜造山带，东起龙门山，经松潘甘孜，向西通过巴颜喀拉，越过 NE—SW 向的阿尔金断裂，连接甜水海地体，往 NW 抵达北帕米尔，长达 1800km, 呈现西部长条状和东部三

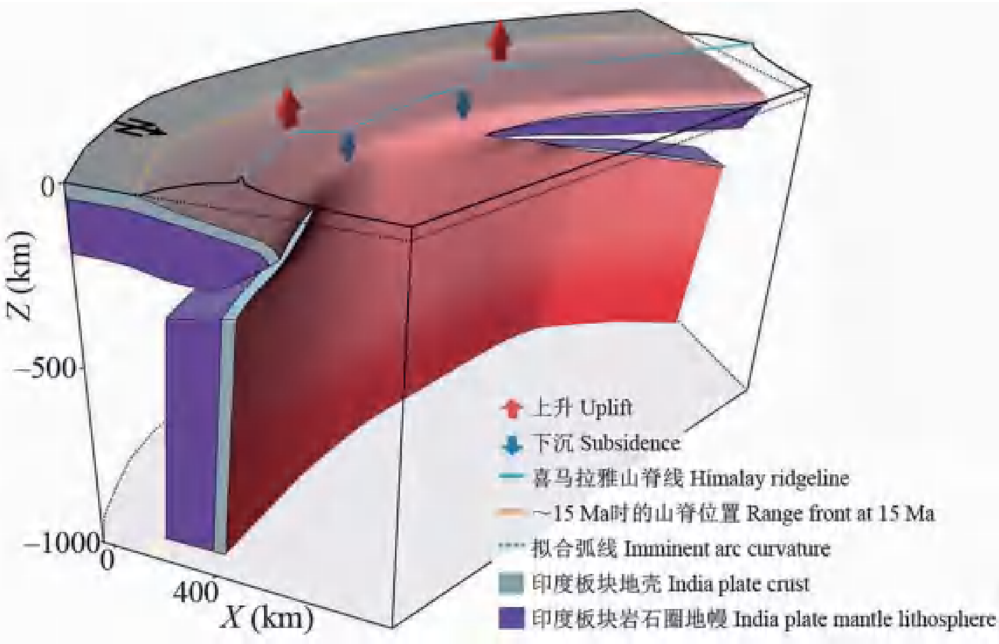

图 15 印度板片断离从喜马拉雅造山带两端向中心的侧向扩展三维图（来自 Webbetal.,2017）

红色阴影代表俯冲的印度板块的上表面，通过释放俯冲板片导致的垂直牵引力，板片断离将影响地形演化，释放动力挠度，并增加板块连续区的垂向载荷（取决于俯冲板块与地幔的黏度比），从而可能产生动态沉降。这一过程可能导致地形在早期沉降之后，再从造山带边缘向中心发生波状抬升。板片断离的横向传播也使造山带弧形弯曲，东喜马拉雅的曲率更大反映了这里板块断离的传播较慢。

角形的几何学特征。松潘甘孜造山带的主体为三叠纪巨厚深海 - 半深海沉积物组成的增生杂岩，在晚三叠世—早侏罗世的造山作用过程中，大量中生代花岗岩侵位以及含锂伟晶岩脉的富集，揭示了锂矿的形成与片麻岩穹隆具有相关性。

片麻岩穹隆指中下地壳热动力学过程产生的，与岩浆作用（或混合岩化作用）密切相关的穹状构造 (Eskola,1949; 许志琴等，2015b)。片麻岩穹隆几乎出露在所有的折返造山带中，反映了所在地区地壳的大幅度抬升。片麻岩穹隆的核部为花岗岩和深熔混合岩，边部为花岗片麻岩，幔部为以高级变质沉积岩和变质火山岩为标志的高角闪岩相到麻粒岩相片麻岩（或高级片岩）。松潘 - 甘孜造山带与锂矿有关的片麻岩穹隆群分布在三叠纪巨厚的富锂深水黏土沉积的空间，由核部中生代花岗岩与幔部经受巴罗式 - 巴肯式变质作用的三叠纪巨厚深海浊积岩组成。

例如：甲基卡和马尔康伟晶岩型锂矿所在的雅江和马尔康片麻岩穹隆群中，幔部的变质由内而外分别为矽线石带（蓝晶石带）、十字石带、红柱石带、石榴子石、黑云母带和绢云母 - 绿泥石带 (Xu Zhiqin et al.,2020;Zheng Yilong et al.,2020)。类似地，北喜马拉雅也拉香波片麻岩穹隆的变质分带自上而下包括：含石榴子石千枚岩和片岩、矽线石 - 蓝晶石 - 二云母片岩、矽线石 - 蓝晶石片麻岩和矽线石 - 石榴子石 - 二云母角闪岩。中压巴罗式变质带是片麻岩穹隆幔部变质的主要特点，后期往往伴随等温减压和降温冷却两个效应。北喜马拉雅 Mabja 片麻岩穹隆的变质分带为：矽线石＋石榴子石＋十字石＋黑云母的矽线石带、蓝晶石＋石榴子石＋十字石＋黑云母的十字石带、石榴子石＋黑云母＋绿泥石的石榴子

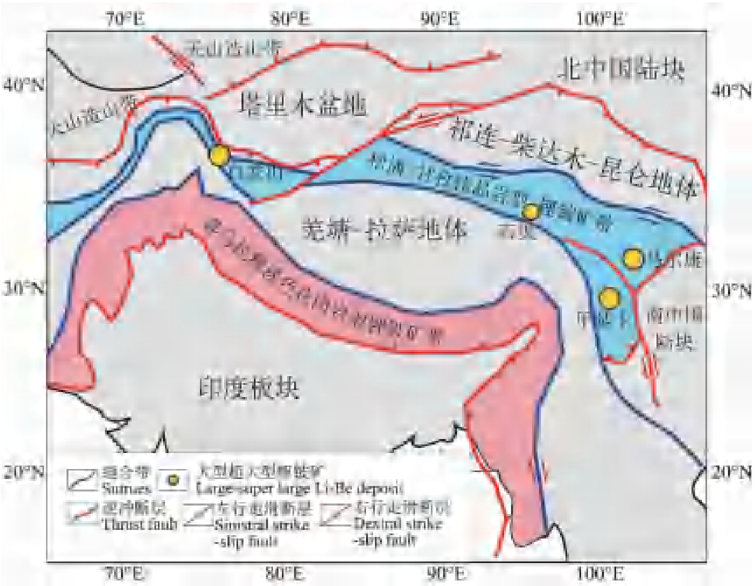

图 16 松潘 – 甘孜和喜马拉雅锂铍矿带位置分布图

石带、绿泥石＋黑云母的黑云母带 (Lee et al.,2004)。这些片麻岩穹隆的变质分带说明中压巴罗式变质作用是片麻岩穹隆幔部变质的主要特点。

片麻岩穹隆的构造成因与锂矿关系成为探讨锂矿成矿规律的关键问题之一。研究表明，松潘甘孜马尔康片麻岩穹隆的起因于造山折返伸展期间（约 210~200Ma) 形成的自北向南的拆离剪切带，其造成的变质核杂岩构造致使核部花岗岩的底辟上升和片麻岩穹隆的形成。而甲基卡片麻岩穹隆至今尚未发现大型韧性拆离构造，“热隆”（许志琴等，1992) 和“底辟”（付小方等，2017) 的观点曾用以解释甲基卡片麻岩穹隆的成因。Whitney(2004) 认为，底辟构造的形成经历从垂直上升的地壳流导致的岩浆上涌的挤压收缩机制到岩体侵位的顶部伸展机制的转化过程。在片麻岩穹隆的深部，流动面理通道以漏斗状为主，在地表则以穹隆状为主，因此片麻岩穹隆是受到从下部岩浆上涌的挤压收缩机制到岩体侵位的顶部伸展机制的转换。

此外，喜马拉雅含稀有金属元素的淡色花岗岩脉的大量发现为新能源矿产资源战略开辟了新的前景（王汝成等,2017)（图 16)。长期以来含稀有元素的伟晶岩被认为是花岗质岩浆分异演化晚期固结的产物 (Cĕrnj，1991;Cĕrnj et al.,2005,2012)。尽管松潘甘孜造山带中大量侵位的中生代花岗岩组成片麻岩穹隆的核部，但是有的花岗岩与伟晶岩锂矿有关，有的却无关，因此，区分两类花岗岩的属性与特征，以及查明花岗岩结晶分异与伟晶岩的成因关系，开展淡色花岗岩、伟晶岩的岩石成因学和成矿学特别是金属区域分带研究，不仅具有重要的科学意义，而且对指导稀有金属矿床的发现具有重要应用价值。

探索稀有金属的“源 - 运 - 储 - 剥”过程与锂超常富集的规律十分重要。研究稀有成矿元素如何从源区析出？通过何种方法运移？怎样在局部聚集沉淀？确定稀有元素的“源 - 运 - 聚”过程是建立成矿理论的核心。

9. 青藏高原的活动断裂带与孕震机制

大地震由断层活动产生，然而，断层的变形行为与破裂过程长期制约着对大地震机制的认识和地震预报的进行。因此，“断层作用”的研究是目前地学界关注的“重大科学问题”(Huntington et al.,2018)。青藏高原是全球大陆内部地震最活跃的地区之一，其中包括青藏高原南缘的喜马拉雅前陆逆冲带和青藏高原北部的松潘甘孜 - 巴颜喀拉地体边界带（图 17)。

9.1 喜马拉雅前陆地震带

自 1505 年有地震记录以来，在喜马拉雅前陆逆冲断裂带发生

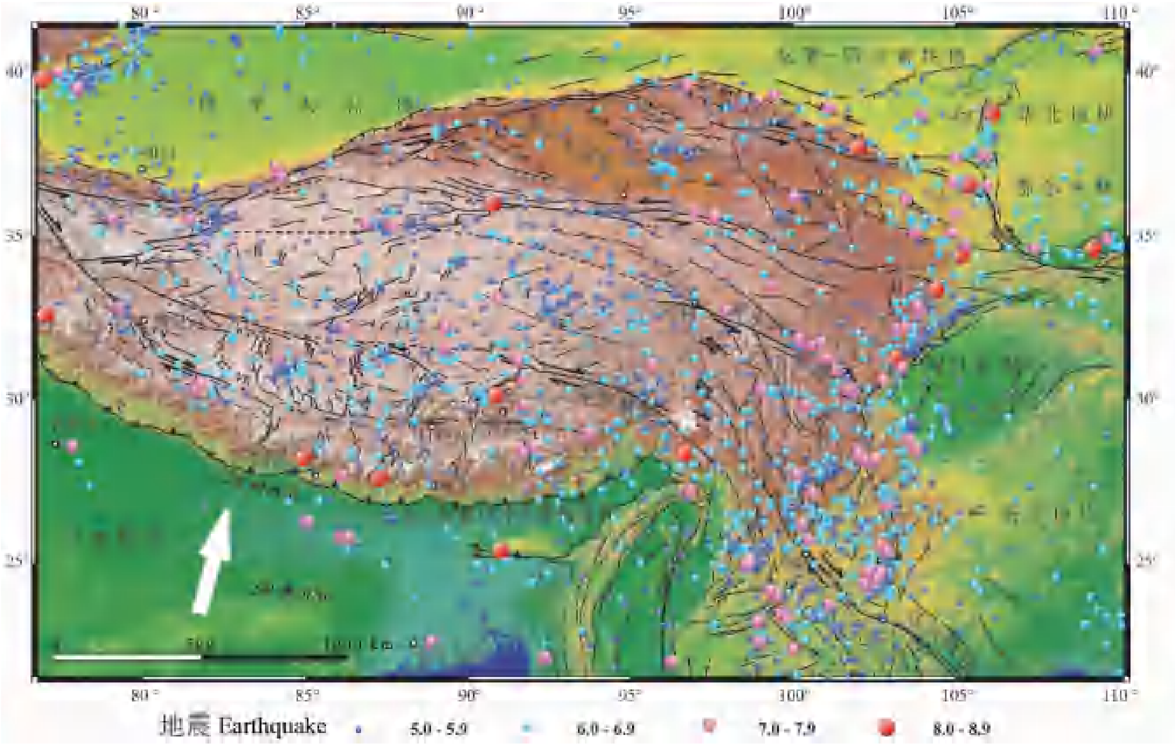

图 17 青藏高原地震分布图（青藏高原主要活动断裂据 Tapponnieretal.,2001）

7.5 级以上地震 8 次，其中最大的有 1950 年的察隅地震（阿萨姆地震）（Ms8.7）、2005 年的喜马拉雅克什米尔地震（Ms7.6）和 2015 年 4 月 25 日尼泊尔地震（Ms7.8）（图 17）。1950 年 8 月 15 日 22 时 9 分 34 秒察隅 - 墨脱发生 8.6 级地震，震中：N28.290° ,E96.657° (Chen Wangping et al.,1977); 震源深度：35km; 该次地震破坏范围长约 330km, 宽约 100km(Coudurier-Curveur et al.,2020)。最远有感距离 1200~1300km。10 度极震区大致沿南伽巴瓦峰东南坡、雅鲁藏布江拐弯下游河谷，以墨脱至里嘎间为中心呈北东向椭圆形，长轴 90km, 短轴 54km（游泽李等，1991）。极震区内房屋全部倒塌，山崩地裂十分严重，雅鲁藏布江多处堵塞断流。地震造成西藏地区死亡 3300 多人；印度阿萨姆地区死亡 1500 多人。它是有记录以来最大的大陆内部地震。

2005 年 10 月 8 日 03 时 50 分 38 秒 在喜马拉雅克什米尔发生 7.6 级地震，震中：N34.460° ,E73.580°（伊斯兰堡东北方 95km 穆扎法拉巴德附近），震源深度：19.1km, 死亡人数：巴基斯坦官方公布 87350 人，印控克什米尔地区造成 1400 人死亡。该次地震的发震断层既不是 MFT, 也不是 MBT, 而是位于次喜马拉雅的 Balakot-Bagh 断层 (Parsons et al.,2005)。地震形成了约 70~110km 的地表破裂带，地表最大垂直位移量约 7m(Avouac et al.,2006;Powali et al.,2020)。

2015 年 4 月 25 日尼泊尔地震（Ms8.1) 由于这次地震断裂分布在低喜马拉雅和高喜马拉雅之下，发震断裂向北延伸至我国境内断层处于更深部位以及可能逐渐转变为韧性断裂 (MHT 从脆性断层转变为韧性剪切带）（图 18), 因此，对我国境内的影响相对较小。

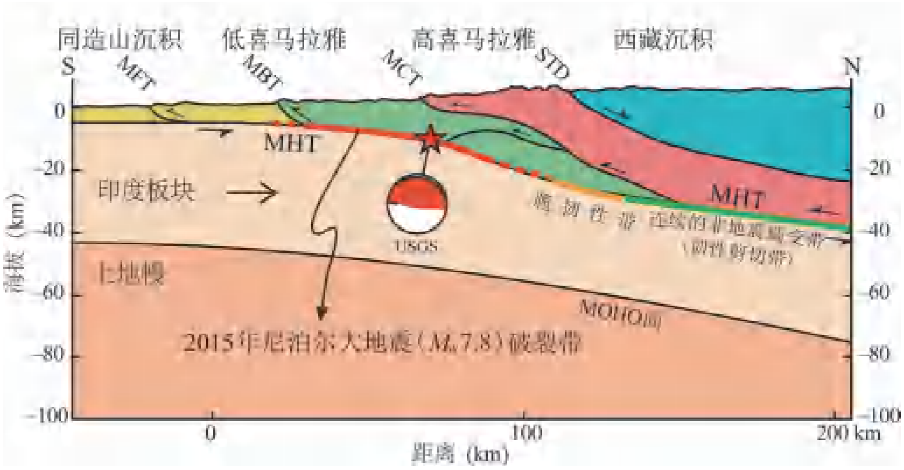

图 18 2015 年 4 月 25 日尼泊尔 Ms8.1 级地震发震构造

MFT—主前锋逆冲断裂；MBT—主边界逆冲断裂；STD—藏南拆离系；MHT—喜马拉雅主逆冲断裂

9.2 松潘甘孜 - 巴颜喀拉地体边界带

值得关注的是近 30 年来青藏高原中部的近东西向的松潘甘孜 - 巴颜喀拉地体的边界上发生了 9 次 7 级以上大地震，其中包括 1997 年 11 月 18 日的玛尼地震（Ms7.9）、2001 年 11 月 14 日的昆仑地震（Ms8.1）、2008 年 3 月 21 日的于田地震（Ms7.3）、2008 年 5 月 12 日的汶川地震（Ms8.0）、2013 年 4 月 20 日的芦山地震（Ms7.0）、2014 年 2 月 12 日的于田地震（Ms7.3）和 2017 年 8 月 8 日的九寨沟地震（Ms7.0），以及 2021 年 5 月 22 日在青海玛多大地震（Ms7.4）（图 19）。上述地震记录表明，松潘甘孜 - 巴颜喀拉地体是近 30 年来青藏高原地震最活跃的地区。分析此地块的地震断裂带的属性既有逆冲断裂（汶川、芦山地震）（LinAimin et al.,2009）、正断层（于田地震）（LiHaibing et al.,2009;XuXiwei et al.,2013），也有走滑断层（昆仑、九寨沟、玛尼、玉树地震）（李海兵等，2021），均沿历史上的薄

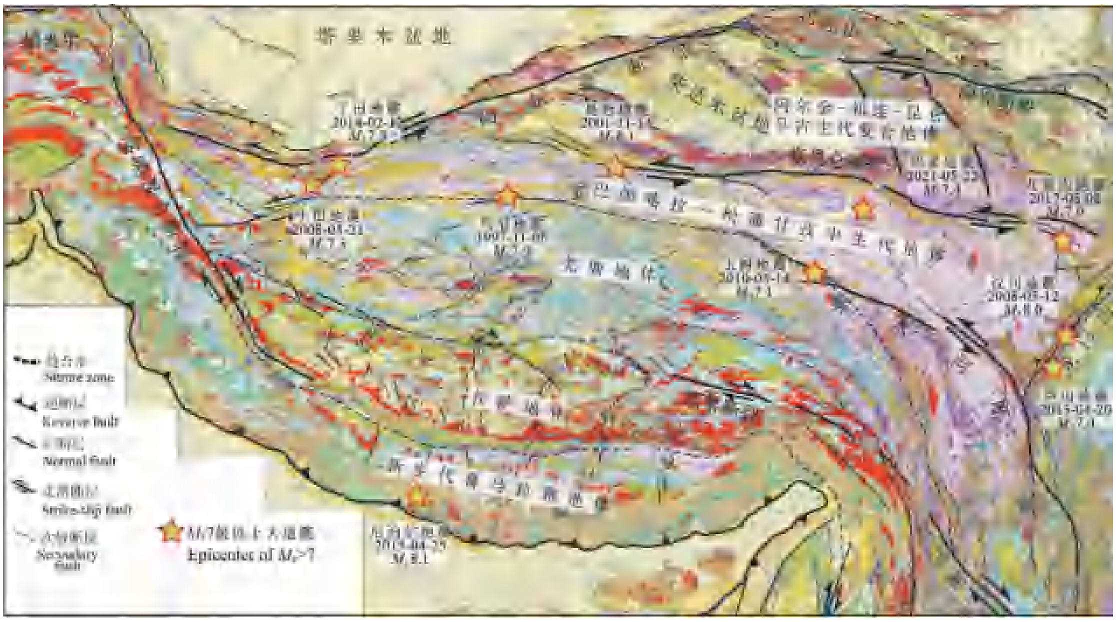

图 19 近三十年来沿巴颜喀拉 – 松潘地块边界发生的 Ms7 级以上大地震（据中国地质调查局成都地质矿产研究所，2004）

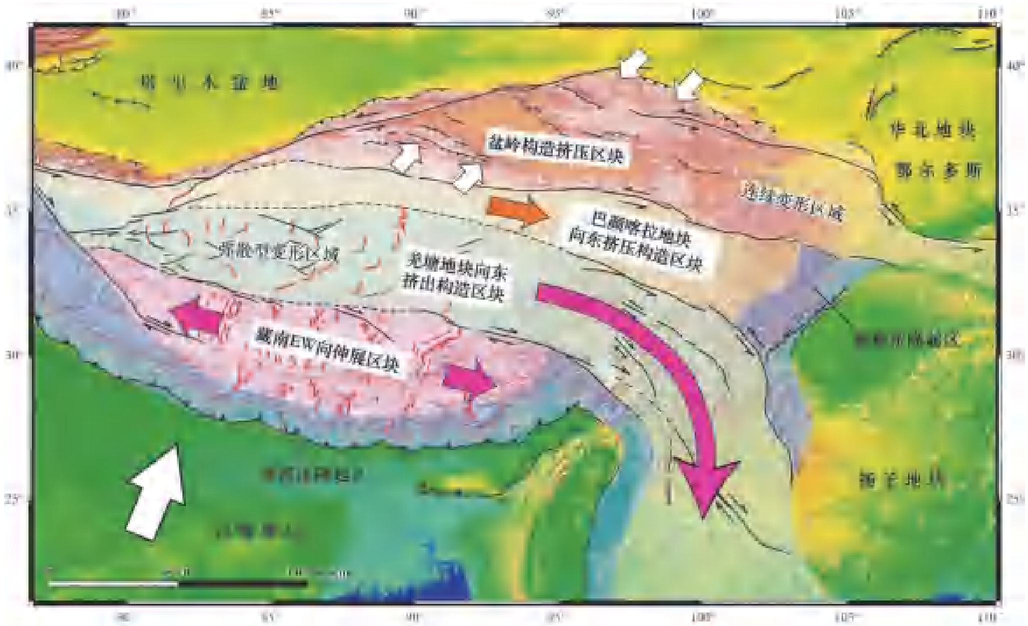

图 20　大型断裂带控制着青藏高原地块的强地震分布和变形演化过程（据李海兵等，2021）

弱带继承性活动，并显示地震迁移具“跳跃性”；而且松潘甘孜地体中的大型走滑断裂（如东昆仑 - 阿尼玛卿左行走滑断裂和鲜水河左行走滑断裂）在诱发地震中起重要作用，反映印度大陆俯冲在亚洲大陆之下造成青藏高原物质的侧向挤出作用：松潘甘孜 - 巴颜喀拉地体向东的侧向挤出受扬子刚性陆块的阻挡以及青藏中部地体向南东的逃逸。

1998 年，中国地震局的一批科学家（张国民、马瑾、邓起东、陈颗、张培震）联合提出中国大陆现今构造变形与强震的“活动地块”假说，用于解释中国大陆强震活动的空间分布规律和现今构造变形作用。活动地块是被形成于晚新生代、晚第四纪至现今强烈活动的构造带所分割和围限、具有相对统一运动方式的地质单元（张培震等，2003; 张国民等，2004)。活动地块内部相对稳定，具有相对统一的运动方式，主要构造变形和强震都发生在边界带上。据记录，中国大陆约 100% 的 8 级以上强震、约 80% 的 7 级以上强震都位于地块的边界带上（马宏生等，2003; 张培震等，2003; 张国民等，2004; 邵志刚等，2008), 估计未来的强震将发生在活动地块边界带内的某些有利部位上，正是由于活动地块的相对运动，才形成了现今构造变形和强震活动的基本格局。

最近，李海兵等根据活动地块的理论，提出青藏高原大型断裂带控制着青藏高原活动地块的强地震分布和变形演化过程，自北而南划分如下活动地块：青藏高原北部盆岭构造挤压块区、向东挤出的巴颜喀拉挤压地块、向南东逃逸的羌塘地块和藏南东西向伸展地块（图 20)。分别受海源走滑断裂、阿尔金走滑断裂、东昆仑 - 阿尼玛卿走滑断裂、龙门山逆冲断裂、嘉黎走滑断裂和喜马拉雅逆冲断裂的制约（李海兵等，2021)。

印度大陆向欧亚大陆俯冲碰撞的动力学过程中如何驱动断裂孕震和发震？这是需要重视和研究的问题，并重新考虑地震的本质和驱动地震的动力。

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剩余部分下期发布）

Editor's Word

In the October of this year, CHYY Development Group Limited entered into an agreement to acquire China Hydrogen Energy (Shenzhen) New Technology Co., Ltd. which added the content of hydrogen fuel cell power system R&D and production to the industrial positioning of CHYY's integrated clean energy systems, and expanded the application of clean energy in mobile systems. As President Xi Jinping pointed out in his written speech at the APEC CEO Summit on 16 November,2023: In recent years, the exports of China's new energy vehicles, lithium batteries, and photovoltaic products have grown rapidly. The upcoming launch of the national greenhouse gas voluntary emission reduction trading market will create a huge green market opportunity. We will accelerate the construction of a modern industrial system, provide better institutional guarantees for all types of business entities to share the fruits of development, and constantly cultivate new growth engines and release greater development space.

CHYY DEVELOPMENT GROUP LIMITED ENTERED INTO AN AGREEMENT TO ACQUIRE CHINA HYDROGEN ENERGY （SHENZHEN） NEW TECHNOLOGY CO., LTD.

Author: SuHailong, HeTianyue

CHYY Development Group Limited (hereinafter referred to as "CHYY") entered into an agreement with China Hydrogen Energy (Shenzhen) New Technology

Co., Ltd. (hereinafter referred to as "CHE") on October 27, 2023. CHYY conditionally agreed to acquire CHE, representing 80% of the company's fully issued share capital, for a maximum total consideration of 70,200,000 HKD. After the transaction, CHE will become a non-wholly owned subsidiary of CHYY, and the financial information of the target group will be incorporated into the financial statements of CHYY.

1. CHYY DEVELOPMENT GROUP LIMITED

CHYY is primarily engaged in the development of clean energy industries: hydrogen energy + geothermal energy. The goal of industrial development is to replace fossil fuel combustion with energy sources that cost no more than traditional energy. Its goal is to ensure the stable supply of electricity, comfortable living conditions for people, and the appropriate temperature of the environment space for the survival and growth of animals and plants, even in the most severe climatic conditions.Provide matching environmental system design schemes and complete sets of products for buildings in different climate regions.Is a clean energy system integrator.

CHYY and CHE participated in the Eco Expo Asia 2023 together

2.CHINA HYDROGEN ENERGY (SHENZHEN) NEW TECHNOLOGY CO., LTD.

The hydrogen fuel cells produced by CHE have significant advantages in high power and long endurance, especially in harsh weather conditions, where their irreplaceable advantages are more evident.

3.CHYY DEVELOPMENT GROUP LIMITED AND CHINA HYDROGEN ENERGY (SHENZHEN) NEW TECHNOLOGY CO., LTD. JOINTLY APPEARED AT THE ECO EXPO ASIA 2023

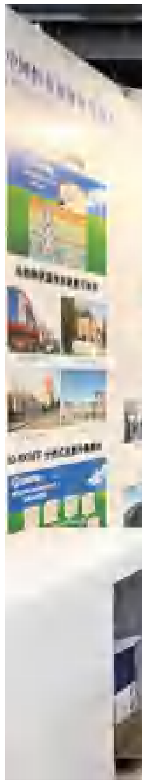
The Eco Expo Asia 2023 was held from October 26 to 29 at the Asia World Expo Convention Center in Hong Kong. CHYY and CHE participated in the exhibition together.

This expo themed "Taking the Leap towards Carbon Neutrality" brings together leading environmental companies from Mainland China and abroad. It aims to promote various environmental concepts such as carbon reduction, circular economy, and new energy. The showcased products cover areas including green buildings, energy efficiency, green transportation, green finance, as well as environmental, social, and governance (ESG).

CHYY is primarily dedicated to the development of the clean energy industry, focusing on hydrogen energy and geothermal energy (heat). Its goal is to replace the combustion of fossil fuels with energy sources that cost no more than traditional energy, providing stable electricity for comfortable living and creating suitable temperatures for the survival and growth of humans, animals, and plants, even in the most adverse climate conditions. The company offers environmental system design solutions and complete products.Its subsidiary CHE is a professional enterprise engaged in the research, development, production, sales of hydrogen fuel cells and power systems, and provides solutions for zero-carbon green transportation, logistics, and combined heat and power (CHP) using hydrogen fuel cell products.

During the exhibition, Academician Wu

Academician Wu Qiang from the Chinese Academy of Engineering (left) visited the company's booth



Qiang from the Chinese Academy of Engineering visited the company's booth and gained a detailed understanding of the company's hydrogen energy and hydrogen fuel cell technology accumulation and product applications. Academician Wu fully acknowledged the development path of "hydrogen energy + geothermal energy (heat)". He expressed that enhancing the development and utilization of hydrogen energy and clean energy is one of the important approaches to achieving green, low-carbon transformation. It is also a significant measure to implement the "emissions peaking and carbon neutrality" strategic goals and sustainable development strategies.

At this exhibition, CHE showcased its independent technological product, a 120KW hydrogen fuel cell power system. The product attracted numerous visitors who came to inquire and explore. The core components of this product have achieved a 100% localization rate, and it has undergone extensive market-oriented validation in terms of safety, reliability, and durability through long-term, multi-domain, and diverse application scenarios. The product has received unanimous recognition from users for its performance in various indicators.

Academician Wu Qiang from the Chinese Academy of Engineering visited the company's booth

During the exhibition, He Tianyue, the Executive Vice President of CHYY, delivered a keynote speech, focusing on introducing the group's core technological products and market application cases. He emphasized that while expanding their existing business, CHYY is actively positioning itself in the field of hydrogen energy applications. The company aims to create zero-carbon, green, and intelligent energy system service solutions. It is gradually improving its application technology in the direction of developing and utilizing green alternative energy sources that are cost-competitive with traditional energy.

The ultimate vision of the company is to gradually realize the substitution of traditional fossil fuel industries with renewable energy fields, focusing on hydrogen energy and geothermal energy (heat).

Following that, Su Hailong, Market Director of CHE, presented the current development status of the hydrogen energy and fuel cell vehicle industries both domestically and internationally. He also introduced the core technological products of CHE and presided over the launch event of the company's globally first independently developed high-power hydrogen fuel cell power system designed for heavy-duty transportation in high-altitude and cold regions.

Exchange during the exhibition

The product has a rated power of 150KW and is primarily suitable for heavy-duty trucks, construction machinery,

He Tianyue, Executive Vice President of CHYY, delivered a keynote speech

Su Hailong, Market Director of CHE, presided over the global launch of the world's first high-power hydrogen fuel cell product

and distributed energy systems for heating, cooling, and power supply. It has made breakthroughs in key technologies such as long endurance, high power, and extended lifespan for hydrogen fuel cell-powered heavy-duty trucks. The product can operate continuously and stably at altitudes of up to 3,000 meters and in temperature ranges from -30 to 85℃, making it suitable for low-temperature and high-altitude environments. The system has a rated mass power density of 647.5W/kg and a service life exceeding 15,000 hours.

After extensive road testing and validation, the 49-ton heavy-duty truck equipped with the hydrogen fuel cell power system has been successfully developed. This truck is designed to operate in high-altitude and cold regions, adapting to different road conditions, seasons, and environmental temperatures. It has also received certification from the Ministry of Industry and Information Technology of China. In the future, we plan to conduct batch deliveries in the Xinjiang region, establishing a demonstration line for hydrogen-powered heavy-duty truck transportation, which will contribute to the region's efforts in achieving the "emissions peaking and carbon neutrality" goals.

Stability and adaptability tests of the vehicles and hydrogen fuel cell power systems conducted under various road conditions

A CASE STUDY OF SHALLOW GEOTHERMAL HEATING AND COOLING THE APPLICATION OF SINGLE-WELL CIRCULATION HEAT EXCHANGE GEOTHERMAL ENERGY ACQUISITION TECHNOLOGY IN HAIDIAN FOREIGN LANGUAGE SCHOOL IN BEIJING AND HEBEI CAMPUS

—— Paper presented at the 2023 World Geothermal Congress

Author: Xu Shengheng,Wang Jiyang,Yang Mingzhong,Li Daqiu

Abstract

Invented by Ever Source Technology Development Co. Ltd., the "single-well circulation heat exchange geothermal energy acquisition technology" is a way to efficiently and safely collect shallow geothermal energy to provide a stable heat source for buildings. This paper introduces the achievements of applying this technology to continuous heating in Beijing Haidian Foreign Language School over the past 20 years. Under the guidance of Academician Wang Jiyang, the case study of the first phase of the project was presented in "Utilization of Shallow Resources-Performance of Direct Use Systems in Beijing" by Shengheng Xu and Ladislaus Rybach at the 2003 annual meeting of Geothermal Resources Council. From 2019, the school expanded its application in the Hebei New Campus project located in Zhangjiakou District of the Beijing Winter Olympic Games to meet the needs of 137000 m^2 buildings in the new campus, including the heating/cooling of various winter sports venues and the provision of domestic hot water throughout the year.

The utilization rate of renewable energy has reached more than 60%, with reduced carbon dioxide emissions exceeding 1976 tons per annual. In this project, the "single well circulation heat exchange geothermal energy acquisition technology" is used to obtain renewable shallow geothermal energy without consuming and polluting groundwater to achieve zero carbon emissions in the region.According to the characteristics of decentralized and functional campus buildings, a water-ring heat pump system with centralized energy collection and distributed cold and heat source stations is set to realize system energy conservation further. Seasonal energy storage is used to store heat energy in summer and winter. Heating and cooling have reached a high energy efficiency ratio.

This paper is a continuation of the paper "Utilization of Shallow Resources-Performance of Direct Use Systems in Beijing". The long-term continuous and stable operation has proved that the single well circulation heat exchange geothermal energy acquisition technology is reliable, simple, reproducible and widely adaptable. It is a preferred technical scheme to achieve the goal of "carbon neutralization and carbon peak" in building heating.

Keywords：Shallow geothermal energy, single-well circulation heat transfer

Introduction

Shallow geothermal energy refers to the heat energy contained within about 100 meters below the surface, and the temperature is lower than 25 degrees centigrade [1]. Shallow geothermal energy is an important part of the geothermal energy family because of its wide distribution, shallowly buried depth, large reserves, and low development and utilization cost. Shallow geothermal energy can be developed and utilized on a large scale, at low cost and stably, by using advanced single-well circulating heat exchange technology. Combined with heat pump technology to improve its heat energy grade (temperature), so that it becomes an alternative energy source for building heating is a convenient low-carbon path to solve building heating. In 2003 Mr. Xu Shengheng and professor Ladislaus Rybach of Zurich University, taking Beijing Haidian Foreign Language School as an example, jointly published the paper “Utilization of Shallow Resources-Performance of Direct Use Systems in Beijing”, for the first time introducing the use of single well-circulating heat exchange geothermal acquisition technology development and utilization of shallow geothermal energy for building heating engineering examples. Adopting single well circulation technology can avoid groundwater recharge difficulties and groundwater resource pollution. Attracted the attention of the conference, and since then, there have been repeated inquiries from the industry. More than 20 years have passed, Haidian Foreign Language School has completed two expansions. Shallow geothermal energy for heating has also developed rapidly in China, and single-well circulation heat transfer technology has been applied to more than 20 million square meters of buildings. This paper takes the study of the latest progress in the Beijing Haidian Foreign Language School heating/cooling system as an example. It introduces its new innovative results and the economic and environmental benefits in response to care from all friends who are interested in the China’s shallow geothermal energy utilization and in the single well-circulating heat transfer technology.

1. INTRODUCTION OF SINGLE WELL CIRCULATING HEAT EXCHANGE GEOTHERMAL ENERGY ACQUISITION TECHNOLOGY

Fig.1 is a schematic diagram of a single well-circulating heat exchange geothermal energy acquisition well. The well’s upper sealing device and the lower sealing device divide the well pipe into three areas, from top to bottom: the pressurized water return area, the sealing area and the pumping area.The well water is pumped by the submersible pump into the heat pump unit to release heat (heating) or absorptive heat (refrigeration) and then returned to the pressurized backwater area. Through the holes on the casing pipe, the water flows out of the well and conducts heat exchange with the surrounding rock and soil. Then through the holes on the casing pipe, the water returns to the water pumping area. The above pumping area and pressurized backwater area should be in the same water layer to realize the same layer recharge [2].

Single well-circulating heat exchange geothermal energy acquisition well can achieve 100% of the same well and the same layer of recharge, avoiding the difficulties in recharge, which is a common problem in the different well systems. The single well-circulating heat exchange can store the heat obtained from the building in summer, and the heat can be used in winter, realizing the winter and summer balance of the underground temperature field around the acquisition well (Fig. 2).

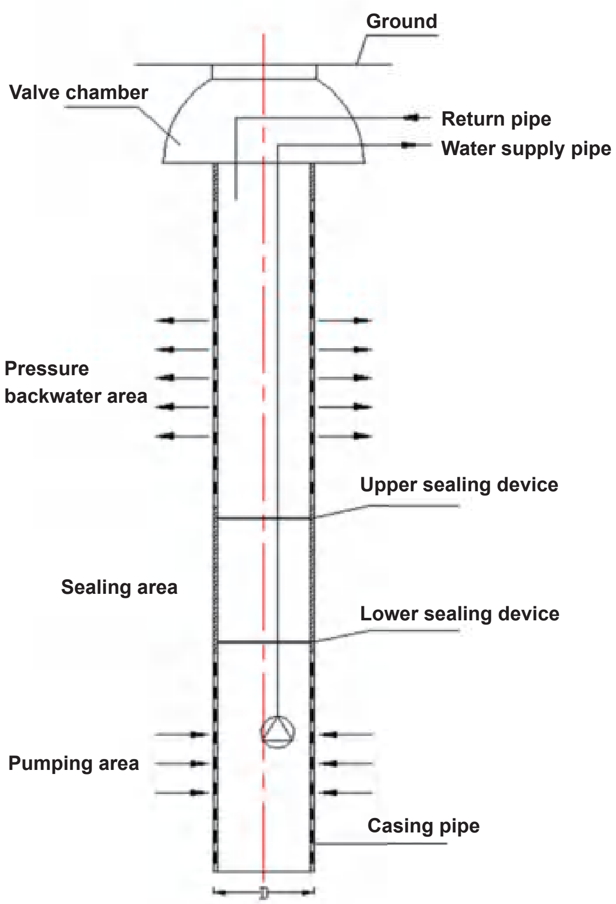


Fig. 1 Schematic diagram of single well circulatingheat exchange energy acquisition well

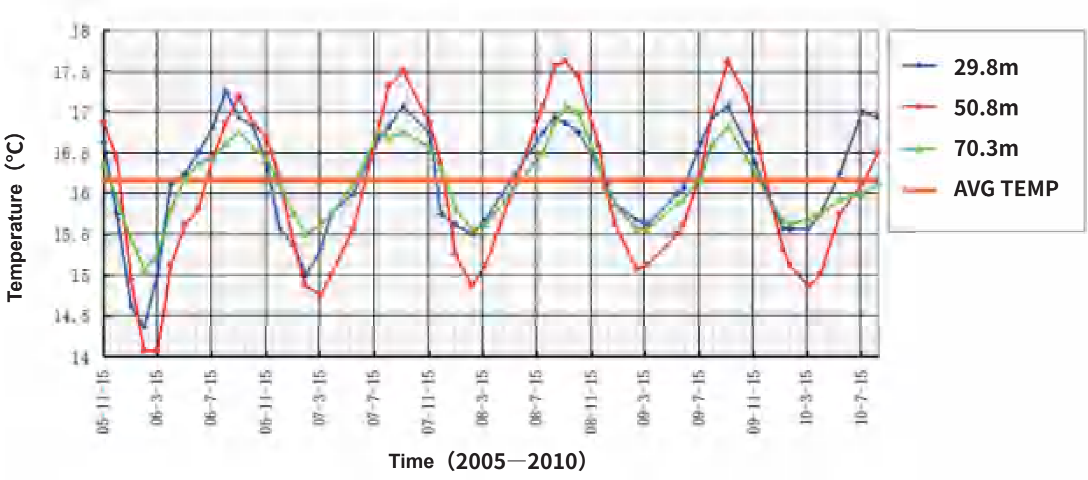


Fig. 2 Underground temperature change curve around of an acquisition well in Beijing

Beijing Water Environment Monitoring Center has tracked and monitored the water quality of single well geothermal energy acquisition wells with circulating heat exchange for 16 consecutive years, and analyzed 21 indicators of the water body, confirming that the water quality has not changed significantly except for the water temperature in the output and re-injection water, and the single well geothermal energy acquisition wells with circulating heat exchange have not affected the groundwater quality.Confirm the water quality has no obvious change and single well circulation heat exchange acquisition well did not affect groundwater quality. After expert review, it is confirmed that single well-circulating heat exchange geothermal energy acquisition well technology neither consumes nor pollutes the groundwater. So it is safe for the groundwater quality[3]. It can provide a large-scale, safe, efficient, and stable acquisition of shallow geothermal energy.

2. OVERVIEW OF HAIDIAN FOREIGN LANGUAGE SCHOOL

The north campus project of Beijing Haidian Foreign Language School is the first phase of the school, with a total construction area of about 60,000 m^2. The south campus project of Beijing Haidian Foreign Language School is the second phase of the school, with a total construction area of about 40,000m^2. Hebei campus is the third phase of the school. It is located in Zhangjiakou city, the city of the Winter Olympics. Zhangjiakou city is in a cold area. Its outdoor meteorological parameters are shown in Table 1. Construction began in 2019, and

Table 1 Outdoor meteorological parameters of Zhangjiakou city

Station location	northern latitude	40° 47′
	east longitude	114° 53′
	height(m)	723.9
Atmospheric pressure (mbar)	Winter	938.9
	Summer	924.4
mean annual temperature (°C)		7.8
Outdoor calculation (dry ball) temperature is (°C)	Winter	-15
	Summer	31.6
Outdoor calculation (wet ball) temperature is (°C)		22.3
The hottest monthly average temperature is (°C)		23.2

all of the projects have completed by 2022. Hebei campus construction area of about 137000m^2 is a new 12-year international school with a capacity of 5,000 students, including teaching buildings, office buildings, scientific research centre, art institute, theatre, staff canteen, student apartment, teachers' apartment, indoor and outdoor sports venues, and other 10 buildings, the project building heat load detailed in Table 2.

Table 2 Building heat and cold load table

Order number	Name of buildings	area (㎡)	Design cold load		Design heat load		Design hot water load (kW)	Winter temperature is (℃)		Summer temperature is (℃)	
			Cold indicator (w / ㎡)	cooling load (kW)	heating index (w/ ㎡)	thermal load (kW)		Winter interior design temperature is (℃)	In Winter, the actual indoor temperature is (℃)	Summer interior design temperature is (℃)	Summer the actual indoor temperature is (℃)
1	1 # Primary school	19731.65	65	1282.56	70	1381.22	890	18～24	19-22	22～26	22-24
2	2 # Middle school	19731.65	65	1282.56	70	1381.22	890	18～24	19-22	22～26	22-24
3	3 # Overseas theater	7473.8	65	485.8	75	560.54	0	18～24	19-22	22～26	22-24
4	4 # Comprehensive Sports Center	4470.04	80	357.6	90	402.3	0	18～24	19-22	22～26	22-24
5	Ski hall	3327.33	80	266.19	90	299.46	0	18～24	19-22	22～26	22-24
6	5 # Ice and snow center	4558.46	80	364.68	90	410.26	293	18～24	19-22	22～26	22-24
7	6 # International Ministry High School	30456.21	65	1979.65	70	2131.93	890	18～24	19-22	22～26	22-24
8	7 # International Department of Junior High School	29849.06	65	1940.19	70	2089.43	890	18～24	19-22	22～26	22-24
9	8 # Kindergarten	14253.35	75	1069	80	1140.27	197	18～24	19-22	22～26	22-24
10	11 # Logistics Office Building	3564.93	75	267.37	80	285.19	141	18～24	19-22	22～26	22-24
11	**amount to**	**137416.48**		**9295.59**		**10081.82**	**4191**				

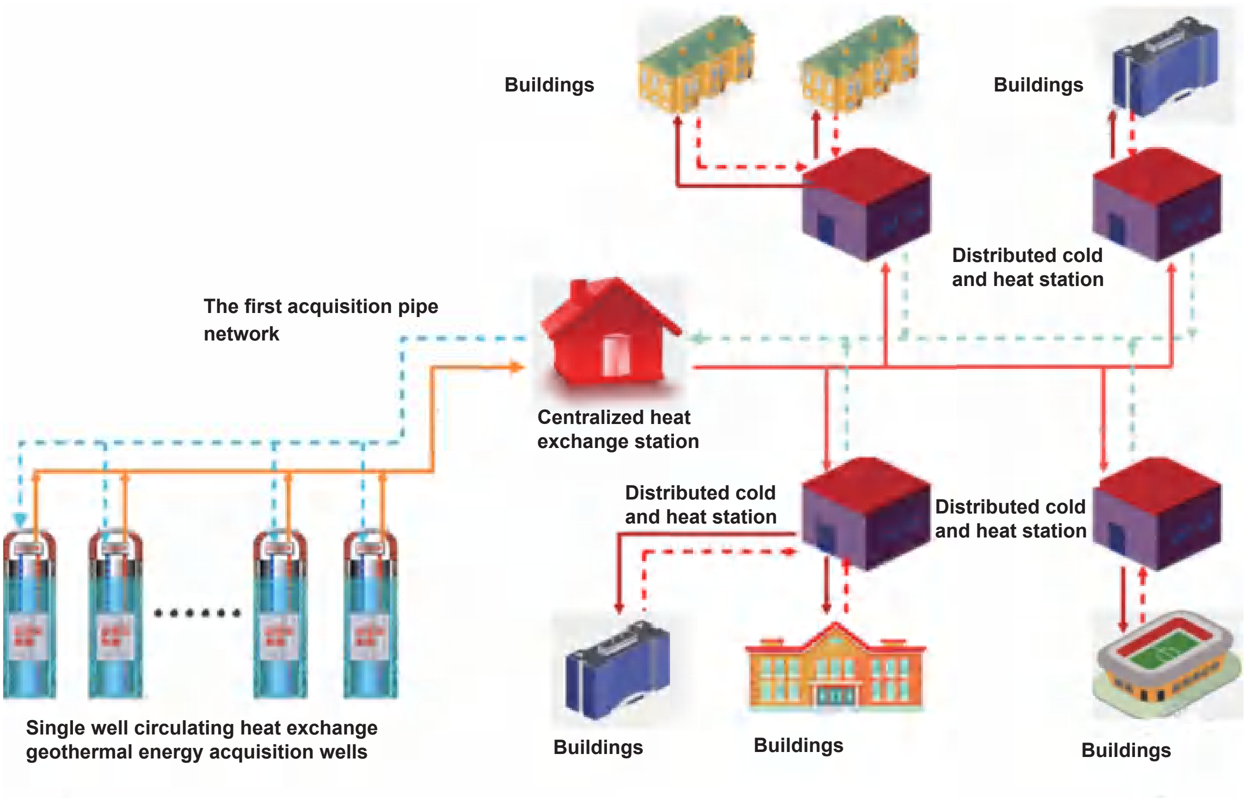


Fig. 3 Principle of distributed cold and heat source system

The project is the Beijing Olympic Education Demonstration School for the 2022 Winter Olympic and Paralympic Games and the ice and snow sports base where the General Administration of Sport of China will reserve Chinese national junior team talents for the Olympic Games.

At present, there are 10 buildings on Hebei Campus. Due to the large campus area, the buildings are scattered, with relatively large surface elevation differences and different use times and frequencies. The shallow geothermal energy distributed cold/heat system is selected for heating /cooling and domestic hot water. The system is composed of multiple single well circulating heat exchange geothermal energy acquisition wells, a shallow geothermal energy centralized heat transfer station, a distributed cold and heat station, and the terminal system in the buildings.

As shown in Fig.3, the multiple single well circulating heat exchange geothermal energy acquisition wells forms an acquisition network. The energy is transferred to the centralized heat exchange station through the first pipe network. By the second pipe network, the heat is distributed to the cold and heat stations, where the temperature will be adjusted for heating or cooling, then through

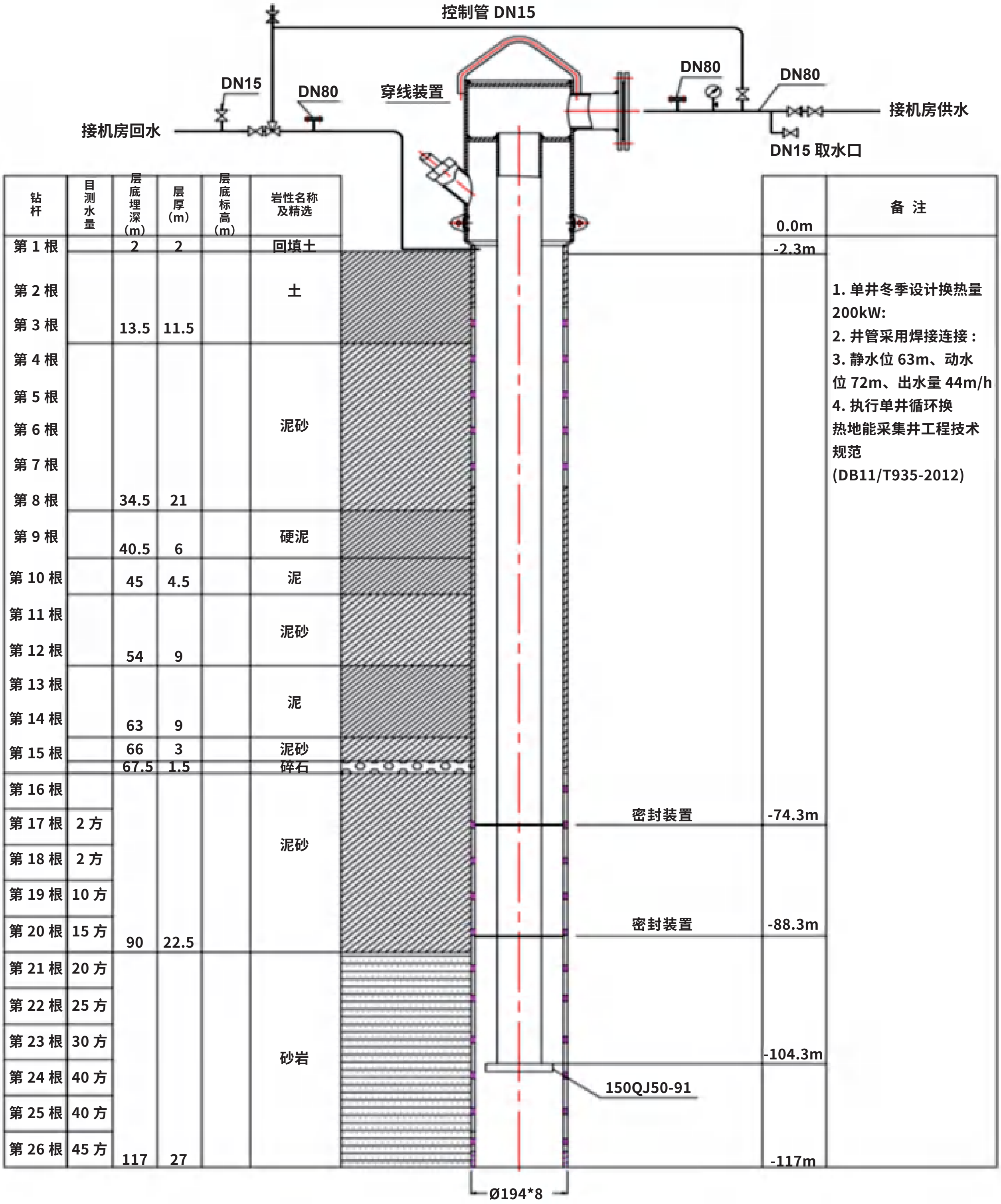


Fig. 4 Map of geothermal energy acquisition well

the third pipe network to the buildings, in which the fourth pipe network distributes the heat or cold to rooms.

3. DESIGN OF SHALLOW GEOTHERMAL ENERGY ACQUISITION WELL

According to the formation lithology of the project location, the main parameters of the acquisition well are:117m deep, the open hole 194mm, and the final hole 194mm (Fig. 4). The project adopts the DTH and pipe drilling technology. Compared with the impact drilling and well-forming technology in the first phase of the school, the new well-forming technology effectively improves the drilling efficiency and reduces the construction cost. After the acquisition well is formed, the acquisition well is tested. The static water level of the acquisition well is 63m, the dynamic water level is 72m, the water output is $44m^3$ / h, and the circulating water quantity is $50m^3$ / h. The water supply temperature of the acquisition well is 15°C and the backwater temperature is 10°C . Well heating (cold) power formula: $N=1.16\times Q\times|T2-T1|$[2].

The heat transfer power of the acquisition well is: $N=1.16\times 50\times|15-10|=290kW$.

4. ENERGY CONSERVATION AND EMISSION REDUCTION EFFECT

4.1 Operation energy consumption statistics

Table 3 Statistical table of energy consumption data in heating Season 2021–2022

<table>
<tr><th>Order number</th><th>Name of buildings</th><th>Area (㎡)</th><th>Cold heat source station system</th><th>Annual heating power consumption (ten million kW .h)</th><th>Annual power consumption (kW .h / ㎡)</th><th>Electricity price (RMB Yuan/ kW. h)</th><th>Annual heating cost (ten thousand yuan)</th><th>Annual square meter heating fee (yuan / ㎡)</th></tr>
<tr><td>1</td><td>1 # Primary school</td><td>19731.65</td><td>1 # Station</td><td>47.85</td><td>24.25</td><td>0.4721</td><td>22.59</td><td>11.45</td></tr>
<tr><td>2</td><td>2 # Middle school</td><td rowspan="2">27205.45</td><td rowspan="2">2 # Station</td><td rowspan="2">50.66</td><td rowspan="2">18.62</td><td rowspan="2">0.4721</td><td rowspan="2">23.92</td><td rowspan="2">8.79</td></tr>
<tr><td>3</td><td>3 # Overseas theater</td></tr>
<tr><td>4</td><td>4 # Comprehensive Sports Center</td><td rowspan="2">7797.37</td><td rowspan="2">3 # Station</td><td rowspan="2">18.02</td><td rowspan="2">23.11</td><td rowspan="2">0.4721</td><td rowspan="2">8.51</td><td rowspan="2">10.91</td></tr>
<tr><td>5</td><td>Ski hall</td></tr>
<tr><td>6</td><td>5 # Ice and snow center</td><td>4558.46</td><td>4 # Station</td><td>6.96</td><td>15.27</td><td>0.4721</td><td>3.29</td><td>7.21</td></tr>
</table>

Order number	Name of buildings	Area (㎡)	Cold heat source station system	Annual heating power consumption (ten million kW .h)	Annual power consumption (kW .h / ㎡)	Electricity price (RMB Yuan/ kW. h)	Annual heating cost (ten thousand yuan)	Annual square meter heating fee (yuan / ㎡)
7	6 # International Ministry High School	30456.21	5 # Station	51.02	16.75	0.4721	24.08	7.91
8	7 # International Department of Junior High School	29849.06	6 # Station	45.55	15.26	0.4721	21.51	7.20
9	8 # Kindergarten	17818.28	7 # Station	38.98	21.87	0.4721	18.40	10.33
10	11 # Logistics Office Building							
11	**amount to**	**137416.48**		**259.03**	**19.30**		**122.29**	**9.11**

4.2 Comparison of operation energy consumption in the first, second and third phases of the school

Table 4 Comparison of operation data of geothermal energy heat pump environmental system of Phase 1, Phase II and Phase Ⅲ projects of Haidian Foreign Language School

Comparison table of operation data of geothermal energy heat pump environmental system in Phase I, Phase II and Phase III of Haidian Foreign Language School			
order number	**Compare the content**	**Phase I and Phase II (Haidian Campus)**	**Phase III (Hebei Campus)**
1	area of structure	100000 ㎡	137416.48 ㎡
2	Heating start time	On October 25	October 15th
3	Heating end time	April 2nd	March 31st

Comparison table of operation data of geothermal energy heat pump environmental system in Phase I, Phase II and Phase III of Haidian Foreign Language School			
order number	Compare the content	Phase I and Phase II (Haidian Campus)	Phase III (Hebei Campus)
4	Refrigeration start time	May 18th	June 8th
5	Refrigeration end time	September 20th	September 15th
6	Water supply temperature of the acquisition well in heating season	16.5°C	15°C
7	Return temperature of water acquisition well in heating season	13.5°C	10°C
8	Water supply temperature at the end of the heating season	42.2°C	42°C
9	End return temperature of heating season	37.9°C	38°C
10	Total energy consumption in heating season	3792000kW.h	2590300kW.h
11	Energy consumption per square meter in the heating season	37.92kW.h	19.3kW.h
12	Water supply temperature of the acquisition well in the cooling season	28°C	20°C
13	Return water temperature of the recovery well in the cooling season	30.3°C	24°C
14	Water supply temperature at the end of the cooling season	13.8°C	12°C
15	End return temperature of cooling season	15.4°C	15°C
16	Total energy consumption in refrigeration season	1474000kW.h	847900kW.h
17	Energy consumption per square meter during the refrigeration season	14.74kW.h	6.17kW.h
18	Total energy consumption for the year	5266000kW.h	3438200kW.h
19	Average annual energy consumption per square meter	52.66kW.h	25.02kW.h

Compared with Phase I and Phase II of the Haidian Foreign Language School Project, the design of the acquisition well system and the primary and secondary pipe networks are more scientific and reasonable, and the annual energy consumption per square meter is reduced by 52.49%.

4.3 Energy conservation and emission reduction achievements

The total energy consumption of the project in the heating season is 2.5903 million kW.h, equivalent to 318 tons standard coal. Compared with direct electric heating, it can save about 800t standard coal, and the utilization rate of renewable energy reaches more than 60%, which can reduce CO_2 every year Emission by 1976 tons, reducing SO_2 emission by 16 tons and dust emission by 8 tons.

5. MAJOR TECHNOLOGICAL PROGRESS AND INNOVATION

In the past 20 years, the single-well circulating heat exchange shallow geothermal energy heating technology has achieved the following developments and innovations:

1) An acquisition well with heat exchange particles is invented. The well water is pumped out by the submersible pump placed in the bottom pumping area of the casing pipe. After entering the heat pump unit to release or absorb heat, the water unit returns to the upper pressurized return water area of the geothermal energy acquisition well.The water flows downward in the annular space with heat exchange particles to the pumping area [2]. Heat exchange particles are placed in the annular

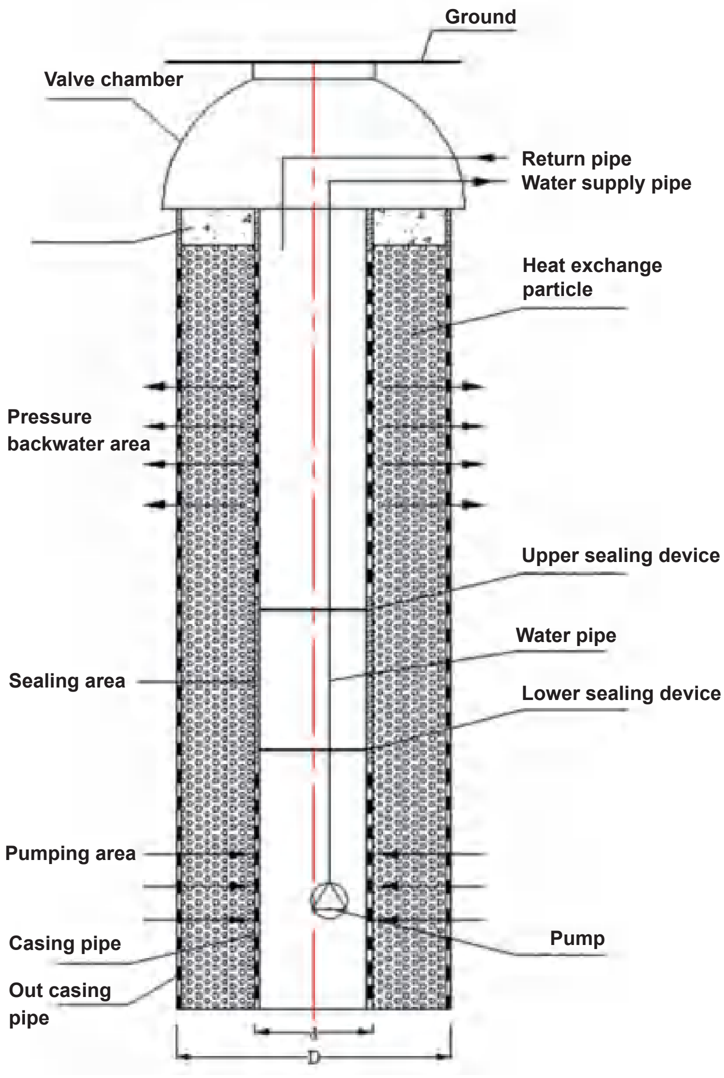


Fig. 5 Acquisition well structure with heat transfer particles

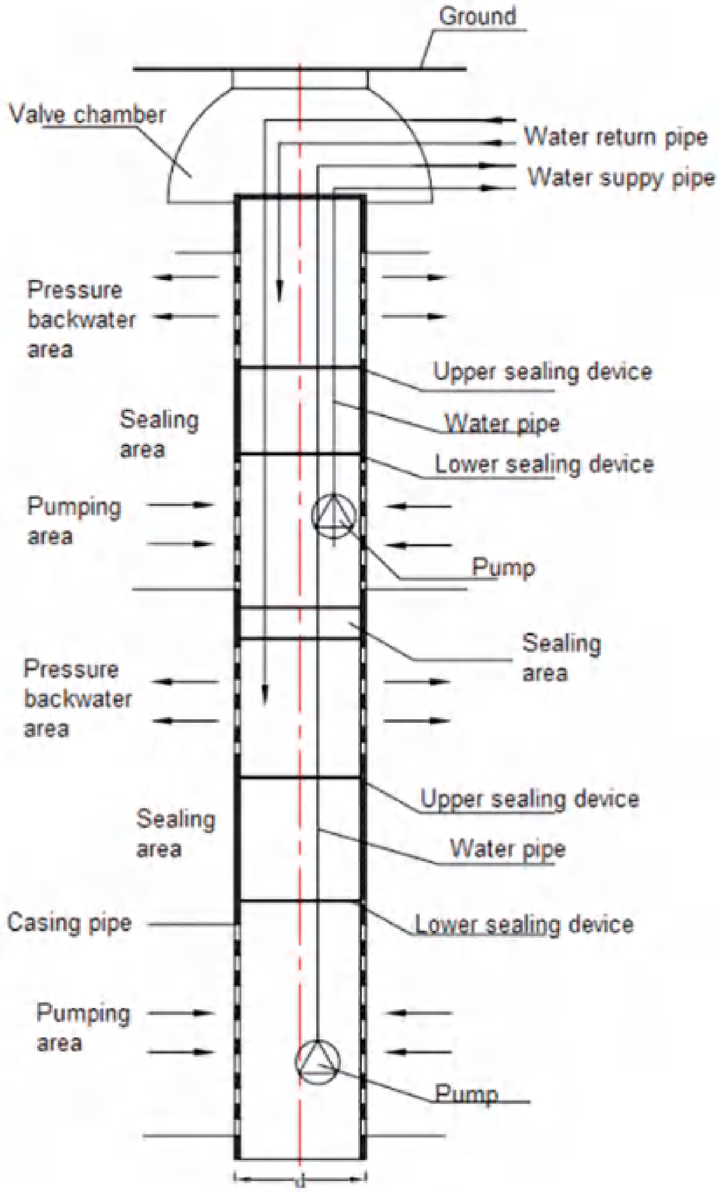


Fig. 6 Multi–aquifer geological structure geothermal energy acquisition well

space around the well pipe to improve the geological environment locally and expand the range of high-efficiency heat transfer (Fig.5). The heat exchange particles should be spherical bodies with a diameter of 10mm-100mm, with a strength greater than 50 MPa [2].

2) In view of the problem of cross-layer pumping in multi-aquifer geological structures, the multi-water layer geothermal energy acquisition technology has been developed. Two or more well stacking and sealing structures are used to realize the same layer recharge of a multi-aquifer geological structure(Fig.6).

3) In 2012, Ever Source Technology Development Group Co., Ltd. compiled the Technical Code for Single Well of Geothermal Energy Collection with Circulation Heat Exchange DB11 / T 935-2012. Beijing Municipal Water Bureau issued it as a local standard, and it provides the specification for the design and construction of the single well-circulating heat exchange geothermal energy acquisition well.

6.OTHER ENGINEERING CASES

Single-well circulating heat exchange geothermal energy acquisition technology has been well recognized and rapidly promoted since its launch in Beijing in 2001. Now it has been extended to large areas in China except Hong Kong, Macao, Taiwan, and Hainan Province. It has been used in a total of more than 800 projects, with a total construction area of more than 20 million m^2. Building types include: government offices, commercial office buildings, residential buildings, large shopping malls, stadiums, archives, hospitals, schools, industrial buildings, landscape pools, etc. Table 5 shows some examples of major works in and around Beijing.

7. CONCLUSION

Shallow geothermal energy is the product of both solar energy and geocentric heat. It is a clean and renewable energy source at temperatures below 25 ℃ . With the help of heat pump technology to change its heat energy grade, winter can be used for heating, and summer can be refrigerated. In the field of construction, alternative energy to heating has great development and utilization value.

Single well-circulating heat exchange geothermal energy acquisition technology is original, advanced, and suitable for a variety of geological conditions. It takes the circulating water as the medium to collect the shallow underground heat energy, which can realize the recharge of

Table 5 Engineering Case Table

Order number	Name	Use	Area of structure(m^2)	Address	remarks
1	The All-China Federation of Industry and Commerce office building	office building	50000	Deshengmen West Street, Xicheng District, Beijing	individual building
2	Haidian Foreign Language School	school	62851	Haidian District, Beijing	
3	Hong Kong and Macao Center, National Academy of Governance	office building	43000	Haidian District, Beijing	
4	The Golden Four Seasons Shopping Center	commerce	116000	Xibei Fourth Ring Road, Dian District, Beijing Municipality	individual building
5	Xiongan Civic Service Center	office building	99600	The Xiongan New Area in Hebei Province	
6	National Grand Theater	landscape	30000	West side of the Great Hall of the People	Landscape pool temperature control
7	Haidian District Rural Application Project	house	800000	Haidian District, Beijing	

the groundwater in the same layer without consuming or polluting the groundwater, so it is safe for the groundwater. Now the technology has gone abroad, and some demonstration projects in the United States have been put into operation.

The Hebei Campus of Beijing Haidian Foreign Language School is a new case of using the single-well circulating heat exchange geothermal energy acquisition technology. The system is more reliable and safe than 20 years ago. The energy efficiency ratio of the system has been improved, and the energy conservation and emission reduction effect has been further enhanced. It can be expected that the single well geothermal energy collection technology for circulating heat exchange will help the development and utilization of shallow geothermal energy to further play its advantages and make contributions to the early realization of the dual carbon goal.

REFERENCE

[1] Xu Shengheng, Ladislaus Rybach. Utilization of Shallow Resources - Performance of Direct Use Systems in Beijing[J], Annual meeting of Geothermal Resources Council, Mexico (2003)

[2] Local Standard of Beijing city. Technical Code for Single Well of Geothermal Energy Collection with Circulation Heat Exchange [S], Beijing: Beijing municipal administration of quality and technology, December 2012, No. DB11 / T 935 - 2012(in Chinese).

[3] Wu Qiang, Xu Shengheng. Numerical Simulation and Analysis based on single - well cycle shallow geothermal energy development [J], Engineering Survey, 1, (2015), 45 - 50.

SHALLOW GEOTHERMAL ENERGY + SOLAR POWER MULTI-ENERGY COMPLEMENTARY HOUSEHOLD HEATING (COOLING) TECHNICAL SOLUTIONS AND CASE STUDIES

—— Paper presented at the 2023 World Geothermal Congress

Author: Liu Baohong, Li Yanchao,Shi Yongliang,Yang Mingzhong,Li Song, Wang Xuezhi,Guan Xiuhu,Xu Shengheng

Abstract

The shallow geothermal energy is used to provide household heating heat source for rural buildings, and the rooftop solar power generation and commercial power are complementary to provide driving power for the heat pump system, which can realize the optimization of environmental and economic benefits. Taking the actual project of Yihepu rural in Zhangjiakou competition area of Beijing Winter Olympic Games as an example, this paper introduces the application and practical benefits of taking shallow geothermal energy + solar power generation energy complementary as household heating (cooling) in rural buildings. By 2022, the project has been stable operation for 6 years, using single well circulating heat transfer technology to collect shallow geothermal energy, centralized geothermal energy exchange and transmission, household heating,the heat pump equipment in each room is independent, successfully solved the rural family heating high energy consumption, poor thermal comfort, points room control difficulty, low distribution network capacity of rural family clean heating common problems, realize the regional heating zero carbon emissions. At the end of this paper, a new generation of low-voltage DC power supply driven multi-energy coupling household heating (cooling) system scheme is proposed, which can realize zero-carbon heating (cooling) in rural buildings.

Keywords： Shallow geothermal energy, Single well circulating heat exchange, Solar power generation, Multi-energy complementary , Household heating (Cooling)

Introduction

Rural areas in northern China have a large population and a wide area, belonging to severe cold or cold regions. Historical reasons cause the poor insulation performance of rural building maintenance structure, the high height, and the building area is generally large, which is 1.5-2 times higher than the heating energy consumption of urban residential buildings[1]. Rural housing needs a " intermittent heating and part of the room heating" heating mode[2]. On the other hand, the rural power supply capacity is limited, it is difficult to realize the conventional electric heating and other electric replacement of coal heating transformation. Rural households need a heating (cooling) system with low power distribution, flexible division control, energy-efficient, environmental protection and economy.

This paper proposes shallow geothermal energy as an alternative energy source for rural building heating in northern China. Solar power generation driven heat pump operation for rural household heating (cold) to provide solutions and attempt to solve the bottleneck problem of clean heating (cooling) for rural households in northern China.

1. TECHNICAL SOLUTION

1.1 Shallow geothermal energy household heating (cooling) system

Shallow geothermal energy is widely

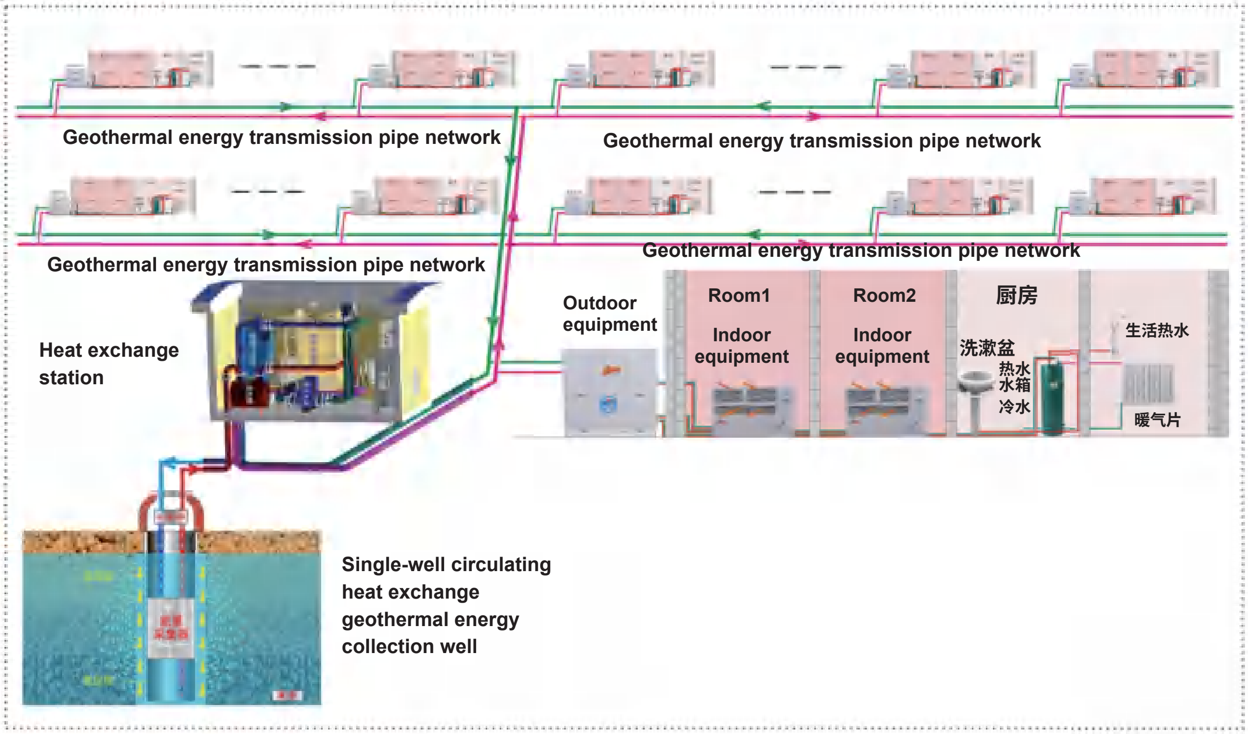


Fig. 1 Schematic diagram of the single-well circulating heat exchange geothermal energy household heating system

distributed and rich in reserves. The single well circulating heat transfer technology to develop and utilize this energy source for heating, cool buildings and make domestic hot water, which has a good energy saving and environmental protection effect[3]. Using single well circulation heat transfer centralized collection shallow geothermal heat energy household heating (cooling) system is referred to as single well circulation heat exchange geothermal household heating system, using centralized geothermal energy heat exchange station, the heat source water with a temperature below 25 degrees Celsius is transported to the heat pump equipment in each room through the geothermal transmission pipe network. The indoor unit of heat pump equipment is heat pump heat fan type similar to ordinary split air conditioning. The system shown in Fig. 1.

The system has the advantages of flexible control and simple operation of ordinary household split air conditioning, which can realize household electric metering and separate room control for home heating (cooling), and the power distribution is lower than ordinary split air conditioning. The differences between single well circulating heat exchange geothermal energy household heating system and ordinary geothermal source heat pump system are shown in Table 1.

Table 1 The differences between single well circulating heat exchange geothermal energy household heating system and ordinary geothermal source heat pump system

System form	Geothermal energy exchange system	Geothermal energy side transmission and distribution system	Heat pump unit	User-side heating (cooling) medium	End equipment	Characteristic
General geothermal source heat pump system for central heating	Centralized collection of geothermal energy	Centralized setting	Centralized setting	Heating (Cooling) water	Radiator; radiant floor; fan coil;	① Can consider the simultaneous use coefficient to reduce the installed capacity; ② Heat source temperature is not less than 35°C , and the transmission and distribution pipe network has heat loss; ③ Big pot rice system, which can not meet the different needs of each household.
Ordinary geothermal source heat pump system for household heating	Collect geothermal energy separately	Household Settings	Household Settings	Heating (Cooling) water	Radiator; radiant floor; fan coil;	① Individual independent, meet differentiated needs; ② Is suitable for buried pipe geothermal energy collection system, drilling area, construction cost is greatly affected by geological conditions; ③ Overall heating, difficult to achieve separate control.
Single-well circulating heat exchange geothermal energy household heating system	Centralized collection of geothermal energy	Centralized setting	Household setting, division and each room matching	Heating (Cooling) gas	Heat pump heat fan	① Geothermal energy collection can consider the same use coefficient, reduce the construction cost; ② Geothermal energy transmission and distribution system for low temperature heat source (25°C) transmission, less heat loss; ③ Can achieve household measurement, separate control, behavior energy saving; ④ 2kW-3kW per household distribution, ordinary split air conditioning distribution can meet the capacity requirements.

1.2 SYSTEM INNOVATION

1.2.1 Indoor unit configured in the sub-room

The heat pump equipment in each room is independent. Therefore, the user can adjust the temperature start and stop, and the temperature in the room can be controlled in the range of 16-32 degrees Celsius. Even if the machine is not running, it will not be frozen. Turn on the equipment when people enter the room, and turn it off when they leave the room. This design innovation avoids the energy waste caused by the heating of the entire building, and is conducive to the realization 'intermittent heating and part of the room heating' heating mode. Geothermal energy household heating equipment is frequency conversion control, adjusting the working frequency of the heat pump unit according to the number of indoor unit used and indoor and outdoor temperature, high efficiency and energy saving.

1.2.2 Floor-type lower air outlet structure heat dissipation design suitable for rural building heating

The indoor unit of geothermal household heating system is a Floor-type lower air outlet structure, which is installed on the ground or 0.2-0.3m wall hanging from the ground. The main air outlet is below and the secondary air outlet is up. The lower air outlet is the main air outlet,while the upper outlet can flexibly adjust the angle of the air outlet, and the warm air heating is directed in the space of the people in the room, so that the active area can quickly heat up.In the special lower outlet air supply the air can flow and spread close to the ground. As the hot wind gradually rises naturally, the temperature of the whole room rises uniformly, to achieve the comfort of floor heating, and the heating speed is fast, as shown in Fig. 2.

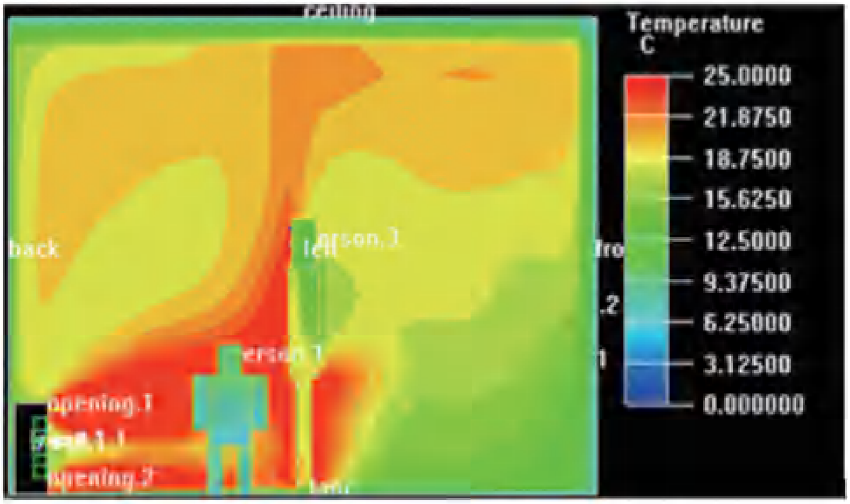


Fig. 2 Floor–type lower air outlet structure heating room temperature field

The temperature of the indoor unit heating room is 3-7 ℃ higher than that of the roof and surrounding space and the heating energy consumption is reduced by about 15%. Floor-type lower air outlet structure heat dissipation makes the room temperature have the effect of a high temperature near the floor space, improves the room temperature and comfort, and solves the problems of large heating energy consumption and low temperature caused by the large space of rural buildings.

1.2.3 Multiple energy sources complement each other

The operation mode of the solar power generation system generate electricity given priority to own use and the rest is sold to the grid. In the transition season, solar power generation is preferentially used in household appliances, the rest electricity is sold to the grid. In the heating (cooling) period, solar power generation is preferentially applied to geothermal energy heating equipment. When the solar power generation is greater than the power consumption, the power consumption of geothermal energy heating system and household appliances is all provided by solar power, When the power is less than the power consumption, the rest is provided by the municipal power grid; The heat of the system comes mainly from shallow geothermal energy, heat pump equipment consumes only a small amount of electricity. [4]

The power consumption of heating and cooling system is less, and the coupling with solar power generation can generate more surplus green electricity, which brings economic benefits, and well solves the demand of heating (cooling) and income generation of rural buildings.

2. DESIGN PARAMETERS AND OPERATING DATA OF THE CASE

Yihepu Rural is located in Huailai County, Zhangjiakou City, near by the the Beijing winter Olympics center. The annual average temperature is 5.5- -6.5 °C , and the heating design temperature in winter is-13.6°C . It is a cold area A. The annual total radiation of solar energy is 5700-6100 MJ / m^2, which belongs to the second class resource area.

2.1 Scheme configuration

The buildings in Yihepu Rural are all single-story buildings, with 370mm red brick wall and no insulation, and the doors and Windows are single-layer wood or single-layer aluminum alloy materials. Each household is 13.2m long from east to west and 7.8m long from north to south, with a heating area of about 100 m^2. According to 18°C in winter and 26°C in summer, the annual heating heat load is 10,478 kW.h, and the annual cooling load is 3,323 kW.h.

The whole rural has 265 households, divided two areas, east and west. Each household designs two geothermal energy household heating equipment, one equipment has 7.6kW heat, input power 1.9kW, the other equipment has 3.7kW heat and input power 0.9kW. Each household solar power generation uses 20 265Wp photovoltaic modules, with a total power of 5.30kWp. The multi-energy complementary power supply system adopts a 5kW photovoltaic inverter, which is connected to the 220V line to the original indoor distribution box of the home, and then connected to the indoor low-voltage distribution network through the

Table 2 The configuration of Shallow geothermal energy + solar power generation multi-energy complementary household heating (cooling) system

Subregion	Number of households (households)	Geothermal energy heat exchange station				Geothermal energy household heating equipment		Solar power generation power (kWp)
		Number of single well (individual)	Submersible water pump power (kW)	Circulation pump power of heat exchange station (kW)	Aggregate capacity (kW)	One drag, one quantity (station)	One drag and two quantity (table)	
Eastern Conference	223	5	55.2	18.5	64.5	223	223	1181.9
Western Conference	42	1	9.2	3	12.2	42	42	222.6

220V line. Shallow geothermal energy + solar power generation multi-energy complementary household heating (cooling) system is configured as shown in Table 2.

2.2 Operating data of the case

In June 2022, the company conducted a field investigation and return visit to the project, to feedback the data of 236 households, and sorted out the system application data for 6 years. There are mainly three types of operating data. The first type is coal burning amount and indoor temperature before renovation; The second type is heating (cooling) power consumption, indoor temperature, indoor heat dissipation equipment startup time and daily living electricity consumption; and the third type is solar power generation and actual income.

2.2.1 Comparison of heating before and after renovation

Before the renovation, farmers burned coal-fired stoves for heating, and manually added coal blocks and removed coal cinders every day. Each household in one season burns is 2.5-3.5t (the calorific value of bulk coal is 5000kcal / kg), equivalent to the standard coal of 1.79-2.5t. There are 75% of the home heating room temperature is lower than 16 ℃ , the room temperature changes greatly with the operation of coal addition, the heating temperature is not stable. After the transformation, the farmer remote control controls the indoor units start and stop, easy to operate. Winter heating power consumption is 2200-3190kW.h, 80% of the user feedback heating room temperature is about 18 ℃ , 20% of the user feedback temperature is more than 20 ℃ , and the geothermal energy household heating

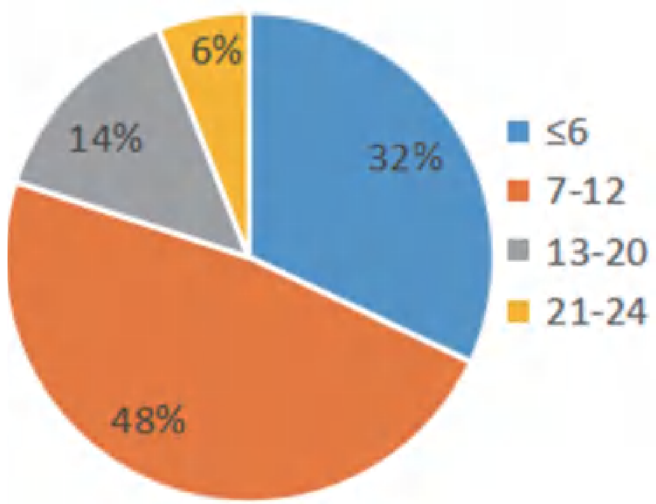


Fig. 3. Table chart of the startup time of the indoor unit

system can be used as a cooling system in summer. Users generally regard it as comfortable and convenient.

2.2.2 Use of the indoor unit

According to the field research and user feedback,most farmers use the mode of " only turning on the indoor unit of the room in use during the day, and only turning on the indoor unit of the bedroom at night" . The boot time cake chart of the indoor unit is shown in Fig. 3. It can be seen that the proportion of indoor units running ≤ 6h and 7h-12h per day accounted for 32% and 48%, respectively, and the number of indoor units running continuously for 21h or more accounted for 6%. The users of continuous use are families with children or sick elderly people. Our specially designed indoor unit with room adjustment conforms to the heating mode of " intermittent heating and part of the room heating" , which meets the habit of 'saving energy' in rural families to the maximum extent, and behavior energy saving and reduces energy consumption.

2.2.3 Annual economic income of families

By 2022, the project has been in stable operation for 6 years. The total power consumption of the geothermal energy household system is 6.00 million kW.h. The total solar power generation is 12.36 million kW.h and the amount of electricity delivered to the grid is 10.26 million kW.h.

The benefits of the multi-energy complementary system from the Zhang's home from August 1,2020 to July 31,2021 are shown in Table 3. The annual power generation is 8183kW.h, the on-grid power is 6955kW.h. Excluding heating and cooling households, the annual electricity consumption is 1,948 kW.h, and the annual power consumption of the heating and cooling households system is 4032.6kW.h. Solar power generation income is 6899.4 RMB, the electricity purchased is 2471 RMB, and the total household net income is 4428 RMB.

3. APPLICABILITY ANALYSIS

3.1 Economic analysis

In the implementation process of rural electricity replacing coal, the life span and maintenance costs of the system equipment are different due

Table 3 The benefits of the multi–energy complementary system

	Transition Season (03.16-06.14,09.16-11.14)		Heating Season (11.15-03.15)		Refrigeration Season (06.15-09.15)		Annual
	Municipal electricity	Solar electrical energy generation	Municipal electricity	Solar electrical energy generation	Municipal electricity	Solar electrical energy generation	
Solar Power Generation (kW.h)		3391.5		2439		2352.5	8183
Solar grid power supply (kW.h)		3319.5		1637		1998.5	6955
Household Consumption (kW.h)	786	72	550	40	470	30	1948
Winter heating and power consumption (kW.h)			1820	762			2582
Power consumption in summer refrigeration (kW.h)					168	324	492
Apalized electricity quantity of heat exchange station (kW.h)			608.6		350		958.6
Electricity income (RMB)		3292.9		1623.9		1982.5	6899.4
Municipal electricity charges (RMB)	-408.7		-1548.9		-513.8		-2471
Total income (RMB)	2884.2		75.0		1468.8		4428.0

to the residents' different choices of heating methods. The annual cost value method is used to calculate the economics of each system. The formula of the annual system cost value Y is:

$$Y = C\frac{i(1+i)^n}{(1+i)^n - 1} + F$$

In: annual value of Y —— system,RMB / a;

C —— system cost,RMB;

i —— Bank interest rate, take 0.0465;

n——system lifetime;year(a);

F Annual operating expenses of the —— system, including electricity charges and maintenance and management costs, RMB / a;

On the premise of meeting the needs of rural households for heating in winter and cooling in summer, analyze the economics of geothermal energy household heating system and solar power generation coupling system and household low temperature air energy heat pump and solar power generation type coupling system, as shown in Table 4.

Table 4 Cost comparison of the system

Heating(Cooling) system	Geothermal energy (Geothermal energy household heating) + Solar power generation	Air energy heat pump + Solar power generation
Heat pump equipment cost (RMB)	28981	18000
Solar power generation equipment (RMB)	33962	33962
Service life (years)	20	15
Annual electricity charge (RMB)	-4428	-2614.2
Maintenance and management expenses (RMB)	629.43	519.62
Annual value of cost (RMB)	1103	2793

Remarks:
① Yihepu Rural shallow geothermal energy household heating (cooling) system investment of 7.68 million RMB, solar power generation system investment of 9 million RMB;
② According to the data in Table 3, the heating heating consumption is 3190.6kW.h in winter and 842kW.h in summer, which all include the shared power of the geothermal energy heat exchange station; the total income of the coupling system is 4,428RMB;
③ Air energy heat pump, the heat fan equipment costs 6000RMB / set[5], Air energy heat pump energy consumption 55.3kW.h/㎡ · heating season[6]The heating energy consumption of a household in winter is 5530kW.h; the refrigeration coefficient is calculated as 3.5, and the refrigeration power consumption is 950kW.h; According to the data of Table 3, the total annual income of the coupling system is RMB 2614.2RMB;
④ Maintenance and management expenses are estimated at 1% of the total system investment.

The annual cost of geothermal energy household heating system+ solar power system is 1252RMB / year, and the annual cost of air energy heat pump + solar power system is 2793RMB / year. The promotion of geothermal energy + solar energy multi-energy complementary system has greater economic benefits.

3.2 Environmental benefit analysis

Environmental benefits mainly come from two parts. The one part is the zero-pollution and zero-emission environmental benefits brought by the system replacing burning loose coal for heating, and the other part is the environmental benefits brought by solar power generation replacing the production and transmission of thermal power plants. Reduction of loose coal according to Technical Guide for Preparation of Air Pollutant Emission List of Civil Coal[7]Calculate the environmental benefits of solar power generation according to China Power Industry Annual Development Report (2017)[8]And the Evaluation Standards for Renewable Energy Building Application Engineering[9]Calculated data, the annual energy saving and emission reduction are shown in Table 5.

Before the transformation, the whole rural burned 567.9t standard coal of loose coal every year, the geothermal energy heating system consumed 846,000 kW.h of electricity every year, the solar energy generated 2.168 million kW.h per year, and the surplus green electricity was 1.322 million kW.h. Annual can reduce carbon dioxide emissions 3101.69t, reduce sulfur dioxide emissions 14.13t, reduce soot emissions 12.36t, with good environmental benefits.

4. NEW GENERATION OF LOW-VOLTAGE DC POWER SUPPLY DRIVEN MULTI-ENERGY COUPLING HOUSEHOLD HEATING (COOLING) SYSTEM

Tsinghua University found that most rural buildings can use their own solar photovoltaic resources to effectively solve their own energy needs and connect excess power to the grid, making rural areas significant solar photovoltaic utilization potential and expected to become an important distributed power source in future zero-carbon power system[10]. Using shallow geothermal energy DC power supply products + rooftop solar power generation + energy storage adjustment multi-energy coupling system can realize home zero carbon heating (cooling) and year-round green electricity.

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Table 5 annual energy saving and emission reduction

	Coal saving capacity (tce)	Carbon dioxidedischarge (t)	Sulfur dioxidedischarge (t)	Smoke emissions(t)
Reduce loose coal by 795 tons	567.85	2082.90	5.88	8.24
The surplus of green electricity is 1.322 million kW.h	412.46	1018.79	8.25	4.12
Gather	980.46	3101.69	14.13	12.36

① According to the Technical Guide for the Compilation of Civil Coal Air Pollutant emission List (Trial), the emission standards of sulfur dioxide and particulate matter are respectively: 7.4kg / t loose coal (the emission coefficient is 7.4St, d, where St, d is 1),10.36kg/t loose coal (bituminous coal dry ash-free volatilization Vdaf is 37%, the soot emission coefficient is 0.28Vdaf=10.36), and the carbon dioxide emission is calculated as 2.62t / t loose coal;

② In 2016, the national standard coal supply consumption of thermal power plants with 6,000 kW and above was 312 g / kW.h.

velopment Group co,Ltd is studying the new generation of DC power supply driven shallow geothermal energy household heating (cooling) products, using 48V low-voltage full DC technology, directly combined with solar power supply. The energy efficiency ratio of 5.5, heating capacity 7500W and heating power 1500W; cooling capacity 8200W and cooling power 1360W; it can be used as a reference for the development of shallow geothermal DC heating (cooling) products.

Schematic diagram of the multi-energy coupled household heating (cooling) system of the new generation of low-voltage DC power supply drive is shown in Fig. 4. The system is composed of DC power supply power system, energy storage system, solar power generation equipment, controller, inverter and other circuit supporting components. In winter heating, the geothermal energy heating system consumes 1 kW.h, transport 4kW.h shallow geothermal energy, and supplies 5 kW.h heat energy to the building . In summer, the four-way valve in the geothermal energy household heating unit can be changed to cool the building. The energy storage system can store excess electricity, which is released at night or in rainy weather to drive the geothermal household heating system, and can also be converted to the electricity power through the inverter and generate economic benefits.

The system uses underground shallow geothermal energy and solar energy; green energy saving; DC power supply without secondary conversion. higher solar power utilization rate; energy storage system makes excess electricity automatic safe storage and increase the proportion of self-use; the system can generate more economic benefits.

5. CONCLUSION

Yihepu Rural shallow geothermal ener-

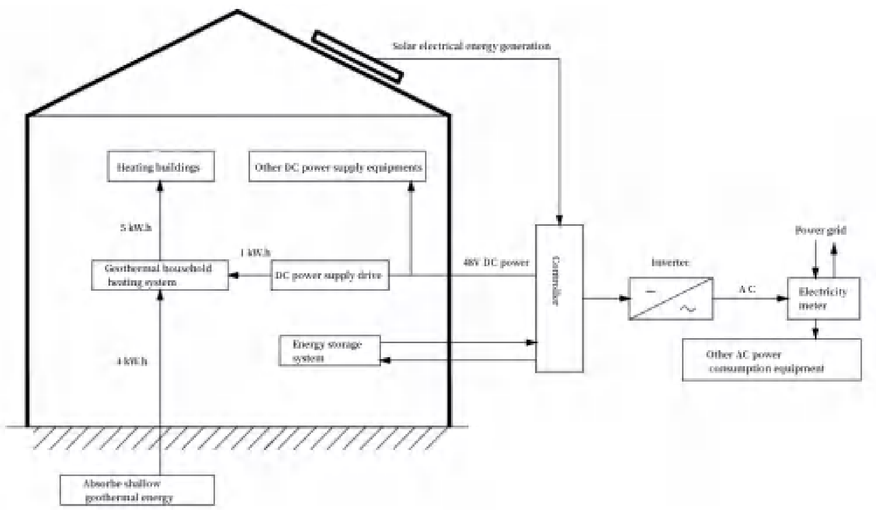

Fig. 4 Schematic diagram of the multi–energy coupled household heating (cooling) system

gy + solar power generation complementary household heating (cooling) system, using shallow geothermal energy for rural building household heating (cooling), using room adjustment and Floor-type lower air outlet structure of geothermal energy heating equipment, with small power distribution, simple operation, separate control, temperature comfort, energy saving, solve the problems of rural building heating, combined with roof solar power generation, can increase economic income for farmers; the system innovative and practical significance of geothermal energy + multi-energy complementary.

In the future, with the listing of DC power supply products, shallow geothermal heating (cooling) + solar power + roof energy storage regulation system can realize family zero carbon heating (cooling) and green electricity, is a kind of rural family energy supply strategy, coordinate the relationship between resources, economy and environment, is conform to the requirements of the "carbon peaking and carbon neutrality" development of rural building new energy system.

REFERENCE

[1] Liu Jing, Zou Yu, Song Bo, Research on the current situation and energy - saving way of rural residential buildings in Cold and Cold Areas [J], Building Science, 2012, no. 012:1 - 5;

[2] Rongjiang Ma, Chunliu Mao, Ming Shan, etal.Occupant control patterns of low temperature air–to–air heat pumps in Chinese rural households based on field measurements [J].Energy and Buildings, 2017, 154 : 157–165 ;

[3] Xu Shengheng, Ryach, utilization of shallow ground energy resources - Example study of single well pumping and irrigation technology [J], Geothermal Resources Council 2003 Annual Meeting;

[4] Wu Desheng, with low - grade energy sources for the heating of buildings is a noble pursuit. [J], China Land energy, 2015, issue 8:30 - 33;

[5] Zibo winter clean heating electric heating equipment air source heat pump heat fan supplier https://www.doc88.com/p–4827396494738.html?s=rel&id=8 ;

[6] Guo Weijiong, Huang Bihe, Zhang Jihuang, The feasibility test analysis of "coal to electricity" technology for clean heating in rural Hebei province [J], power demand side management, 2019,21 (02): 46–50;

[7] Technical guide for the compilation of civil coal air pollutant emission list (trial);

[8] Annual China Power Industry Development Report (2017);

[9] Renewable Energy Building application Engineering evaluation standard, GB / T 50801–2013:24–26;

[10] Liu Xiaohua, Zhang Tao, Liu Xiaochen, Jiang Yi, the development status and research outlook of the new energy system of "light storage and direct softness" buildings [J / OL], HVAC, 2022;

https://kns.cnki.net/kcms/detail/11.2832.TU.20220516.1224.002.html

REVISITING THE TEN KEY GEOSCIENTIFIC PROBLEMS IN THE QINGHAI-TIBET PLATEAU

—— 《ACTA GEOLOGICA SINICA》 100th Anniversary

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Abstract

This paper reexamines the key scientific issues of the Qinghai-Tibet Plateau, providing new clues for solving the "landing" problem of plate tectonics theory, and providing new ideas for understanding the evolution of continental lithosphere and its energy resources, geological hazards and global environmental effects at the plate convergence boundary. In this paper, ten key geological problems of the Tibetan Plateau are discussed as follows: ① The Indian continental Northward drift model; ② Initial collision time between India and Asia; ③ Paleo Tethys orogeny in the Tibetan Plateau; ④ Crustal shortening in the Paleogene Himalayan orogenic belt; ⑤ the deep melting mechanism of the high Himalaya; ⑥ The time limit and difference of the uplift of the Qinghai-Tibet Plateau; ⑦ Structure-denudation-climate interaction and South Asian monsoon; ⑧ Distribution and origin of key mineral resources on the Qinghai-Tibet Plateau; ⑨ Active fault zone and seismogenic mechanism of the Qinghai-Tibet Plateau; ⑩ What is the course of the Indian Plate after the collision? Deep dynamic processes. These problems can be regarded as the focus of the current research on the continental dynamic evolution of the Qinghai-Tibet Plateau.

Keywords： Qinghai-Tibet Plateau; Plate tectonics; Dynamics of continents

As the highest, largest, thickest and newest plateau in the world, the Qinghai-Tibet Plateau is the optimal laboratory for developing solid earth science theories. The study of the Qinghai-Tibet Plateau has a history of more than 200 years since the beginning of the Himalayas. Re-examining and exploring the key scientific issues of the Qinghai-Tibet Plateau can provide important new information for the study of the evolution of the continental lithosphere and its energy resources, geological hazards and global environmental effects at the plate convergence boundary, and make contributions to solving the "landing" problem of the plate tectonic theory. The Indo-Asian collision is the most spectacular geological event since the Cenozoic era, resulting in the rise of the Himalayas, the uplift of the Tibetan Plateau, the formation of the extremely thick crust, the mass escape of the Tibetan Plateau to the east, southeast and southwest, the dispersion and deformation of the inner Asian continent within 2000km, the basin system and oil and gas resources around the Tibetan Plateau, the South Asian monsoon and Asia.

Inland drought, etc. The author puts forward the following key geological questions for the study of the Qinghai-Tibet Plateau: ① The Indian continent North drift model; ② Initial collision time between India and Asia; ③ Paleo Tethys orogeny in the Tibetan Plateau; ④ Crustal shortening in the Paleogene Himalayan orogenic belt; ⑤ the deep melting mechanism of the high Himalaya; ⑥ The time limit and difference of the uplift of the Qinghai-Tibet Plateau; ⑦ Structure-denudation-climate interaction and South Asian monsoon; ⑧ Distribution and origin of key mineral resources on the Qinghai-Tibet Plateau; ⑨ Active fault zone and seismogenic mechanism of the Qinghai-Tibet Plateau; ⑩ The fate of the Indian subduction Plate after the collision -- Deep dynamic processes. This essay commemorates the 100th anniversary of the Geological Journal.

7.Tectonic-denudation-climate interactions and the South Asian monsoon

It has long been publicly recognized that the tectonic evolution of the solid Earth has important effects on the atmosphere and oceans. The uplifting of mountain ranges and the opening and closing of oceans and basins control the circulation of water and atmosphere on a global scale, which in turn affects regional climate and rates of erosion (molnar et al.,1993,2010).As a result, rising plateaus and mountains can disrupt atmospheric circulation (Manabe et al.,1974),and due to denudation and sediment transfer are closely related to climate change, the change of rainfall pattern has an important influence on the duration and geometry of orogenic belt structure, and can promote the deep rock return (Beaumont et al.,2001;Sinclair et al .,2005;Wobus et al.,2005). (Similarly, the opening and closing of oceans can shift warm currents to high latitudes, influencing regional or global climate change over time scales of more than a million years or more, with the Asian monsoon system considered the most explicit example. The South Asian monsoon refers to the monsoon in southern Asia (typical of the Indian Peninsula), also known as the "Indian monsoon". It is generally believed that the cause of its formation is the seasonal movement of the earth wind belt, the sea-land thermal difference, the topographic factors of the primary and Himalayan terrain uplift, the northern hemisphere or global climate change and the causes of the Indian monsoon have become important scientific issues (An Zhisheng et al.,2001;Beaumont et al.,2001).

But how do climate and plate subduction dynamics interact? What came first and what came last? The "chicken and egg" scenario limits our understanding of the "climate-erosion-tectonic" interaction. The existence of a large number of thrust fault systems during Himalayan orogenesis in a collision environment has long been recognized. However, the greatest contribution to the understanding of Himalayan stress regulation should be the discovery of the Southern Tibet detachment System (STD) (Burchfield et al.,1992).Therefore, the return of the high Himalayan amphibolite facies is believed to be the result of crustal tunnel flow held by the southern Tibet detachment system and the main central thrust fault extrud-

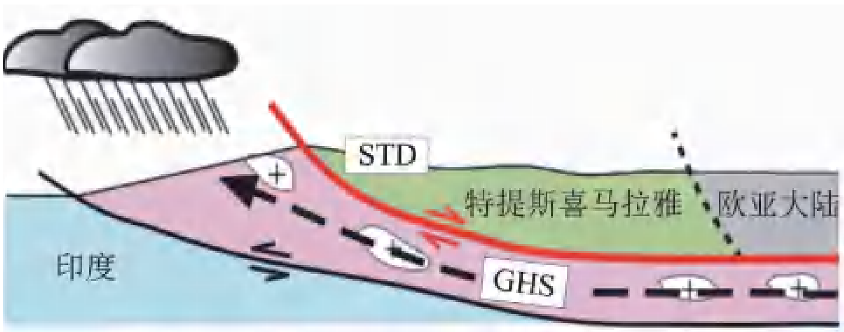

Fig.14 Mid-crustal “channel flow” model of the Greater Himalaya

GHS—Great Himalaya Sequence;STD—South Tibet Detachment ing southward at about 23-17 Ma under the influence of rapid surface denudation caused by precipitation at the southern foot of the Himalayan orogenic belt (Fig.14) (Beaumont et al.,2001),a model which has attracted widespread attention (Searle et al .,2005;Godin et al.,2006;Hodge,2006).

In the early 1990s, attempts were made to link the evolution of the Indo-Asian collision tectonics to the intensity of the monsoon around 8 Ma (Kroon et al.,1991;Prell et al.,1992). However, a large number of studies have shown that the occurrence time of strong monsoon is much earlier than the original understanding. It may start from the Eocene, intensify in the early to middle Miocene, and then the middle to late Miocene (about 12 ~ 8 Ma) has a dry climate, rather than a period of strong monsoon rain (Clift et al.,2018).

Clift et al.(2018)suggested that the South Asian monsoon is the product of the Himalayan barrier effect, which provides a new mechanism to explain the summer heavy rainfall in the early to Middle Miocene. The rapid reentry of crustal materials in the high Himalaya basically coincided with the strong monsoon period caused by climate change in the early to middle Miocene, which means that the surface erosion rate was accelerated at this stage, promoting the reentry of deep materials.

However, it has recently been recognized that the reentry time of high-pressure metamorphic rocks along the strike of the high Himalaya is intertemporal with the associated tectonic movements. Webb et al. (2017), according to the results of previous studies on magmatic activity and metamorphism and chronology of the Himalayan orogenic belt, found that the whole high Himalaya experienced a transition from progressional metamorphism to regressive metamorphism in 26 ~ 2 Ma. Along the orogenic belt trend, the activity stop time of the southern Tibet detachment system was earlier in the east and west tectonic tectonics (about 24 ~ 20 Ma). The middle part is late (about 13 ~ 11 Ma). This trend may be controlled by the dynamics of the subduction plate. The subduction Angle of the Indian plate became steeper in 30-25 Ma, resulting in the plate segment extending from the edge to the middle, and the tectonic uplift changing along the strike, resulting in the strengthening of the Himalayan arcuate mountain system and the South Asian monsoon (Fig. 15). Therefore, the time of uplift and its spatio-temporal variations over the Tibetan Plateau and Himalaya are crucial to understanding the tectonic-denudation-geomorphic coupling process.

Clift et al.(2018) reviewed the history of the South Asian monsoon, it is estimated that the monsoon was a period of intense rainfall at 24 Ma, a peak wet period at 15 Ma, and a dry period at 8 Ma. These ages are associated with the uplift of the Tibetan Plateau-Himalaya and the withdrawal of sea water. In particular, the rapid Himalayan

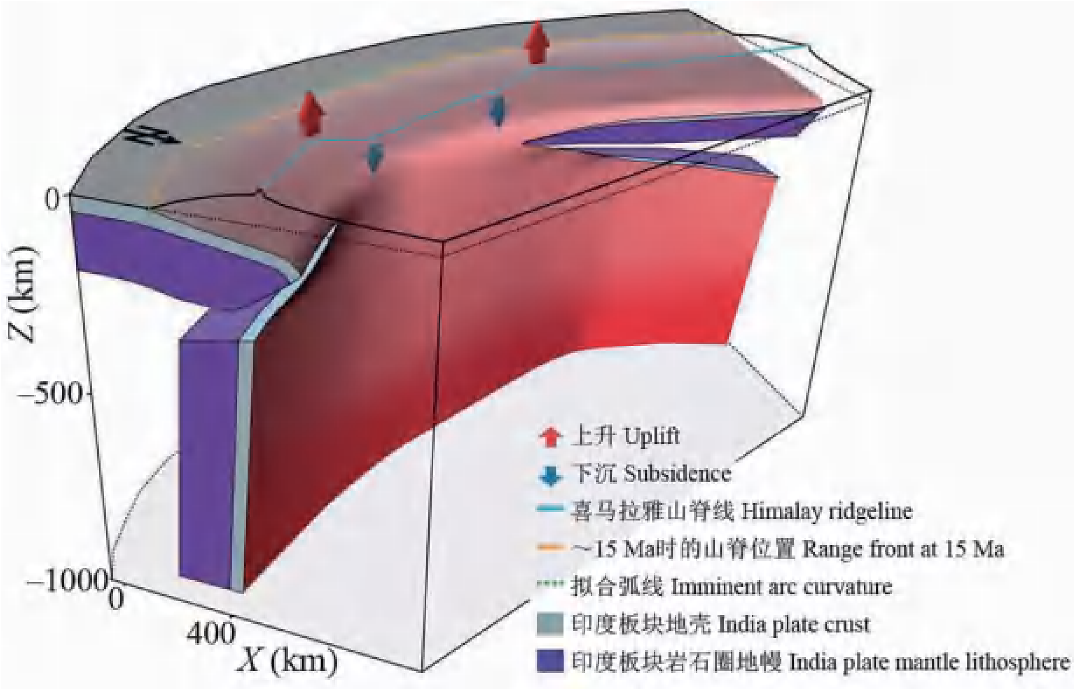

Fig. 15 The Indian plate segment is separated from the Himalayan orogenic belt from both ends towards the centerLateral extension 3D diagram (from Webbetal., 2017)

The red shadows represent the upper surface of the subducting Indian plate. By releasing the vertical traction caused by the subducting plate, the plate fragmentation will affect topographic evolution, release dynamic deflection, and increase the vertical load on the plate continuum (depending on the viscosity ratio of the subducting plate to the mantle), which may result in dynamic subsidence. This process may have resulted in a wave uplift of the terrain from the edge to the center of the orogenic belt after early subsidence. The lateral propagation of plate fragmentation also makes the orogenic belt curved, and the greater curvature of the Eastern Himalayas reflects the slower propagation of plate fragmentation here.

uplift of the Mesocene provided a sudden geomorphic barrier to northbound summer monsoons and rainfall, deflecting the west-to-east airflow, which may continue to the present day (Molnar et al.,2010).

8.Distribution and origin of key mineral resources in Qinghai-Tibet Plateau

Lithium - beryllium - tantalum rare metal has become an important strategic and key mineral resource, and is one of the key minerals for the development of new energy industry, guarantee and sustainable development of social economy. In recent years, with the rapid development and continuous breakthroughs in fields such as lithium batteries, new energy vehicles and controlled nuclear fusion, lithium's strategic position has been continuously enhanced and it is known as the "energy metal of the 21st century". The Qinghai-Tibet Plateau, which is composed of Tethys terrains, is an important gathering place of key mineral resources in mainland China, among which the metallogenic potential of rare metals is the weakest part in the resource response of the Qinghai-Tibet Plateau. Nowadays, with the implementation of the "new energy mineral resources strategy", the discovery of large and super-large lithium deposits such as methyl Ka, Malkang and Balongshan in Songpan-Ganzi orogenic belt has attracted great attention from domestic and foreign counterparts, and the Songpan-Ganzi orogenic belt may become a supernormal lithium enrichment zone associated with Be, Nb, Ta, Sn, Rb and Cs elements (Fig.16;Xu et al.,2015b,2018;Fu et al.,2017;Xu et al.,2020).

The Songpan Ganzi orogenic belt, located in the central and northern part of the Qinghai-Tibet Plateau, starts from Longmen Mountain in the east, passes through Songpan Ganzi, passes Bayan Khara in the west, crosses the NE-SW Altyn fault, connects with Tianshui Haitian body, and reaches North Pamir in the NW with a length of 1,800km, showing geometric features of long strip in the west and triangle in the east. The Songpan Ganzi orogenic belt is mainly composed of accretive complex composed of super-thick abyssal and semi-abyssal sediments in the Triassic. During the Late Triassic to Early Jurassic orogenic process, a large number of Mesozoic granite embeds and the enrichment of Li-bearing pegmatite dials reveal the correlation between the formation of lithium ore and the gneiss dome.

Gneiss domes are dome-like structures generated by thermodynamic processes in the middle and lower crust and closely related to magmatism (or mixed lithification) (Eskola, 1949; Xu et al., 2015b). Gneiss domes appear in almost all of the receding orogenic belts, reflecting significant crustal uplift in the region. The core of the gneiss dome is composed of granite and deep mélange, the edges of the dome are com-

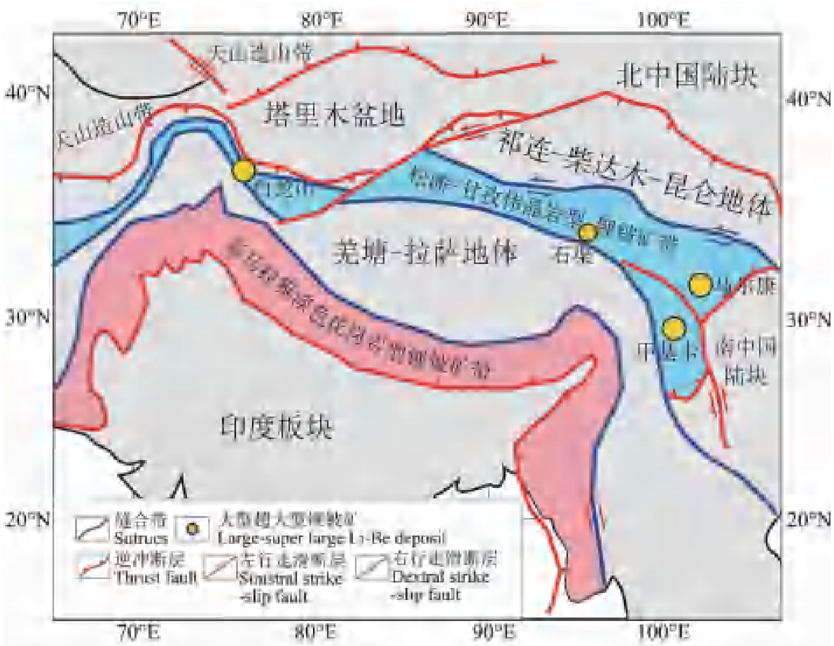

Fig.16 Distribution of the lithium–beryllium deposits in the Songpan–Ganze and Himalaya orogenic belts

posed of granitic gneiss, and the mantle is composed of high amphibolite to granulite gneiss (or high schist) marked by advanced metamorphic sedimented and metamorphic volcanic rocks. The lithium-related gneiss domes in the Songpan-Ganzi orogenic belt are distributed in the space deposited by super-thick lithium-rich deep-water clays in the Triassic. They are composed of Mesozoic granites in the core and super-thick deep-sea turbidites in the mantle subjected to Baro-Bakken metamorphism. For example, in the Yajiang and Malkang gneisses domes, where the methyl ka and Malkang pegmatite lithium deposits are located, the metamorphism in the mantle is divided from the inside out into the silonite zone (klanite zone), the cross stone zone, the andalusite zone, the garnet zone, the biotite zone and the sericite-chlorite zone (Xu et al., 2020; Zheng et al., 2020). Similarly, the metamorphic zonation of the Yalashambast gneisse dome in the northern Himalaya includes, from top to bottom, garnet-bearing phyllite and schist, skarine-kyanite-bismicite schist, skarine-kyanite-bismicite gneisite, and skarine-garnet-bismicite amphibolite.

The barotropic Barro metamorphic zone is the main characteristic of the mantle metamorphism of the gneiss dome, which is often accompanied by two effects of isothermal decompression and cooling in the later period. The metamorphic subzones of the Mabja gneisses dome in the northern Himalayas are: silica + garnet + crossstone + biotite silica zone, kyanite + garnet + crossstone + biotite tite tite zone, garnet + biotite + chlorite garnet + biotite zone, chlorite + biotite biotite zone (Lee et al., 2004). These metamorphic zonings of gneiss domes suggest that barotropic Barlow metamorphism is the dominant feature of the mantle metamorphism of gneiss domes.

The relationship between the tectonic genesis of the gneiss dome and the lithiumore has become one of the key issues in the exploration of lithiumore mineralization. The results show that the Songpan Ganzi Malkang gneiss dome was caused by the north-to-south detachment shear zone formed during the orogenic extension period (about 210 ~ 200 Ma), and the metamorphic core complex structure caused by it led to the diapir rise of the core granite and the formation of the gneiss dome. However, no large ductile disassembling structures have been found in the methyl carniite dome so far. The viewpoints of "hot rise" (Xu et al., 1992) and "Diapir" (Fu et al., 2017) have been used to explain the genesis of the methyl carnite dome. Whitney (2004) believed that the formation of the diapir structure experienced a transformation process from the compression and contraction mechanism of magma upsurge caused by vertical crustal flow to the top extension mechanism of rock emplacement. In the deep part of the gneiss dome, the flow bedding channel is mainly funnel-shaped, while on the surface it is mainly dome-shaped. Therefore, the gneiss dome is transformed from the compression and contraction mechanism of magma upwelling below to the top extension mechanism of rock emplacement. In addition, the extensive discovery of pale-colored granite dikes containing rare metallic elements in the Himalayas opens up a new prospect for a new energy mineral resource strategy (Wang et al., 2017) (Fig. 16). Pegmatite containing rare elements has long been considered to be the product of late consolidation of granitic magmatic differentiation evolution (Cěrnj, 1991;Cěrnjetal.,2005,2012).

Although a large number of Mesozoic granites in the Songpan Ganzi orogenic belt compose the core of the gneiss dome, some granites are related to pegmatite lithium ore, while others are not. Therefore, it is necessary to distinguish the properties and characteristics of the two types of granites and identify the genetic relationship between the crystalline differentiation of granites and pegmatite. It is not only of great scientific significance but also of great application value to guide the discovery of rare metal deposits to study the petrogenesis and metallogenesis of pale granite and pegmatite, especially the regional zonation of metals.

It is vital to explore the "source- transport-storage-stripping" process of rare metals and the rule of lithium supernormal enrichment. How do rare ore-forming elements precipitate from the source area? By what means? How do you collect sediments locally? Determining the "source-transport-accumulation" process of rare elements is the core of establishing metallogenic theory.

9.Active fault zones and seismogenic mechanism of the Tibetan Plateau

Large earthquakes are generated by fault activities. However, the deformation behavior and rupture process of faults restrict the understanding of large earthquake mechanism and earthquake prediction for a long time. Therefore, the study of "faulting" is an important scientific question in the field of geography (Huntington et al., 2018). The Tibetan Plateau is one of the most seismically active regions in the global continental interior, including the Himalayan foreland thrust belt in the southern margin of the Tibetan Plateau and the Songpan Ganzi - Bayankhara terrane boundary belt in the north of the Tibetan Plateau (Fig. 17).

9.1 Himalayan foreland seismic zone

Since the advent of earthquake records in 1505, there have been eight earthquakes of magnitude 7.5 or greater along the Himalayan foreland thrust fault zone, The largest of these are the 1950 Chayu earthquake (Assam earthquake) (Ms8.7), 2005 Himalayan Kashmir earthquake (Ms7.6) and April 25, 2015 Nepal earthquake (Ms7.8) (Figure 17). August 15, 1950 at 22:9 minutes 34 seconds Chayu - Motuo 8.6 magnitude

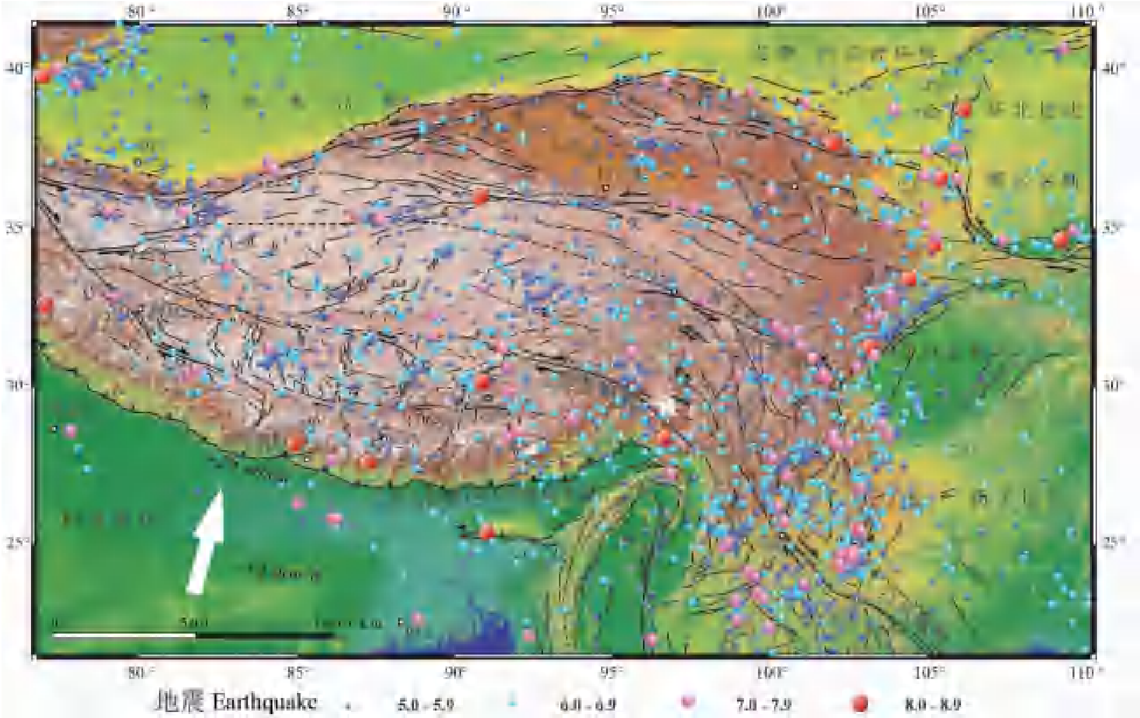

Fig. 17 Earthquake distribution of Tibetan Plateau (active faults on the Tibetan Plateau after Tapponnier et al.,2001)

earthquake, epicenter: N28.290 °, E96.657 ° (Chen Wangping et al.,1977);depth of hypocenter 35 km approximate damage area at 330 km long width at 100 km (Coudurier. Curveur et al.,2020). Farthest sensory distance was at1200~1300 km. The 10 degree extreme earthquake area is roughly along the southeast slope of the Nangabawa peak and the downstream valley of the Yarlung Zangbo River bend, with the center between Metuo and Riga as an ellipse, with a long axis of 90km and a short axis of 54km (You et al., 1991). All houses in the quake zone collapsed, the mountain collapsed and the Yarlung Zangbo River was blocked and disconnected in many places. The quake killed more than 3,300 people in Tibet; More than 1,500 people died in India's Assam region. It was the largest intra-continental earthquake ever recorded.

A 7.6-magnitude earthquake occurred in the Himalayan region of Kashmir at 3:50.38 seconds on October 8, 2005. The epicenter was N34.460 °, E73.580 ° (near Muzaffarabad, 95km northeast of Islamabad), the focal depth was 19.1 km. The death toll: Officials in Pakistan put the death toll at 87,350 and in Indian-administered Kashmir at 1,400. The seismogenic fault of this earthquake is neither MFT nor MBT, but the sub-Himalayan Balakot-Bagh fault (Parsons et al., 2005). The rupture zone of about 70 ~ 110km was

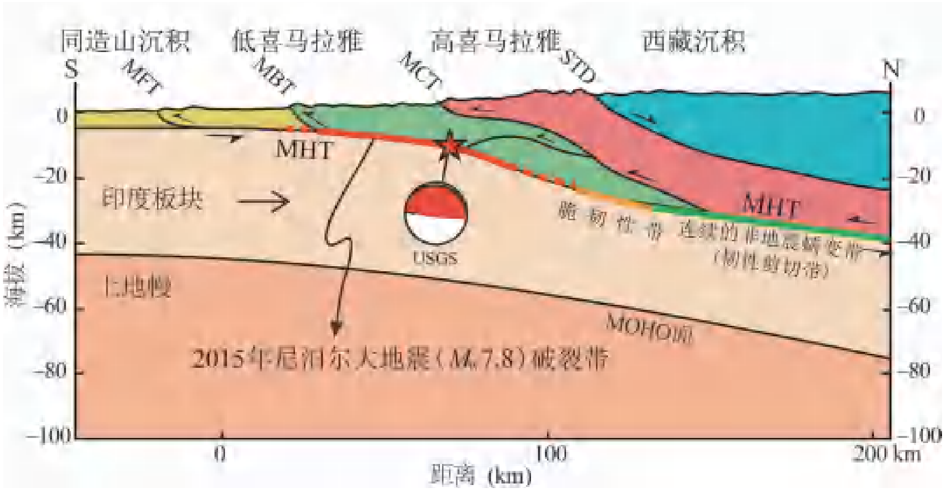

Fig.18 Seismogenic tectonics of Ms8.1 Nepal earthquake, 25 April ,2015

MFT – main Frontal Thrust ; MBT – Main Boundary Thrust;STD – South Tibet Detachment; MHT – Main Himalayan Thrust

formed by the earthquake, and the maximum vertical displacement of the surface was about 7 m(Avouac et al.,2006;Powali et al.,2020).In the Nepal Earthquake on April 25, 2015 (Ms8.1), since the seismic faults were distributed under the lower and higher Himalayas, the seismo-induced faults extended northward to the fault in China, which was in a deeper part and may gradually transform into ductile faults (MHT changed from a brittle fault to a ductile shear zone) (Fig. 18). Therefore, the impact in our country was relatively small.

9.2 Songpan Ganzi - Bayan Khara terrane boundary zone

It is worth noting that in the past 30 years, there have been 9 large earthquakes of magnitude 7 or above along the boundary of Songpan Ganzi and Bayankhara in the central part of the Qinghai-Tibet Plateau. These include the Mani earthquake (Ms7.9) on November 18, 1997, Kunlun earthquake (Ms8.1) on November 14, 2001, Yutian earthquake (Ms7.3) on March 21, 2008, Wenchuan earthquake (Ms 8.0) on May 12, 2008, and 2013 Lushan Earthquake (Ms7.0) on April 20, 2014, Yutian Earthquake (Ms7.3) on February 12, 2014, Jiuzhaigou earthquake (Ms7.0) on August 8, 2017, and Maduo Earthquake (Ms7.4) in Qinghai Province on May 22, 2021 (Fig. 19). The above seismic records show that Songpan Ganzi - Bayankhara terrane is the most seismically active area in the Tibetan Plateau in the past 30 years. The attributes of the seismic fault zone in this block are analyzed as the thrust faults (Wenchuan and Lushan earthquakes) (Lin et al. , 2009), normal fault (Yutian Earthquake) (Li et al. , 2009; Xu et al., 2013), there are also strike-slip faults (Kunlun, Jiuzhaigou, Mani, Yushu earthquakes) (Li et al., 2021), all of which have inherited activities along the histori-

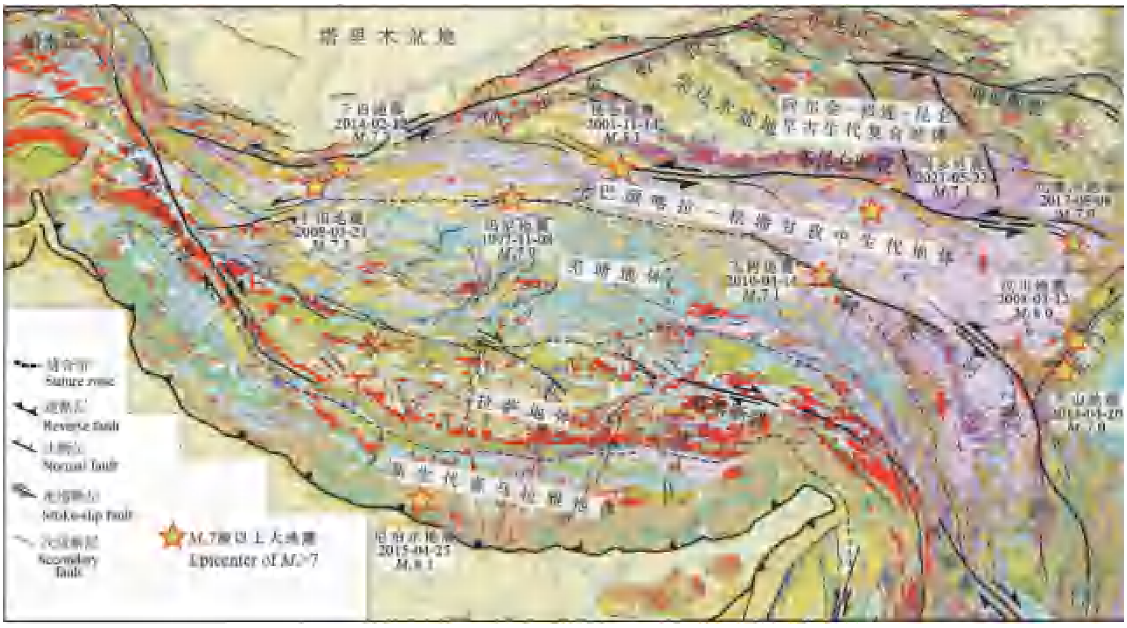

Fig. 19 >Ms7 large earthquake in Tibetan Plateau,mainly along boundary of the Bayanhar–Songpan terrane (modified after Chengdu Institute of Geology and Mineral Resources,CGS,2004)

cal weak zone, and show that the seismic migration has a "jump; Moreover, large strike-slip faults in the Songpan Ganzi terrane (such as the East Kunlun - Anemqing left strike-slip fault and the Xianshuihe left strike-slip fault) played an important role in the earthquake, reflecting the lateral extrusion of Tibetan Plateau material caused by the subduction of the Indian continent under the Asian continent: The lateral extrusion of Songpan Ganzi - Bayankala terrane to the east is blocked by the rigid landmass of the Yangtze and the escape of the central Tibetan terrane to the southeast.

In 1998, a group of scientists in the China seismological bureau (Guo-min zhang, Ma Jin, deng east, Chen Yong, Pei-zhen Zhang) jointly produced a structure of deformation and earthquake "plot" hypothesis, which is used to this day, to explain China's large land spatial distribution regularity of strong earthquake activity and tectonic deformation effect. The active block is a geological unit which is divided and confined by the tectonic belt formed in late Cenozoic and from late Quaternary to the present (Zhang et al.,2003;2004).The interior of the active block is relatively stable and has a relatively uniform movement mode. The main tectonic deformation and strong earthquakes occur in the boundary zone. About 100% of strong earthquakes of magnitude 8 or above and 80% of strong earthquakes of magnitude 7 or above in mainland China have been recorded to be located in the boundary zone of the block (Ma et al., 2003;

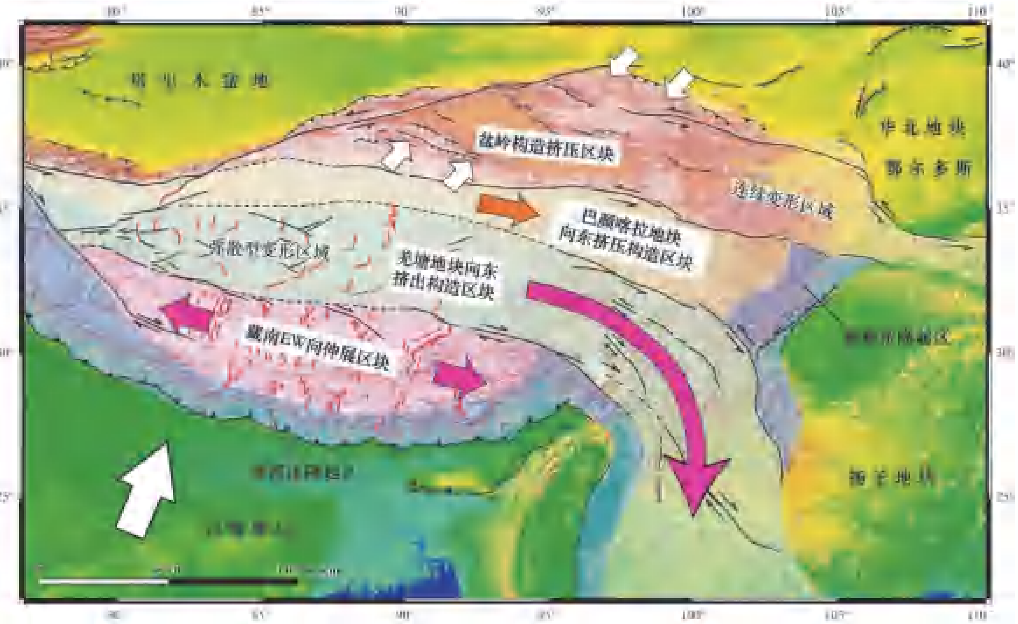

Fig.20 large earthquake and deformation controlled by large fault system in Tibetan Plateau(after Li Haibing et al.,2021)

Zhang et al., 2003; Zhang et al., 2004; Shao et al., 2008), estimated that future strong earthquakes will occur in some favorable locations within the boundary zone of active blocks. It is because of the relative movement of active blocks that the basic pattern of current tectonic deformation and strong seismic activity has been formed.

Recently, based on the theory of active blocks, Li et al. proposed that the Qinghai-Tibet Plateau large fault zone controls the strong earthquake distribution and deformation evolution process of the active blocks on the Qinghai-Tibet Plateau, which are divided into the following active blocks from north to south: the north of the Qinghai-Tibet Plateau Penling tectonic extrusion block, the eastward extruding Bayanjala extrusion block, the southeast escaping Qiangtang block, and the east-west South Tibet extension plot (Fig. 20). They are respectively constrained by the Haiyuan strike-slip fault, Altun strike-slip fault, East Kunlun - Animachen strike-slip fault, Longmen Shan thrust fault, Jiali thrust fault and Himalaya thrust fault (Li et al., 2021). Nevertheless, how does the dynamic process of subduction and collision between the Indian continent and Eurasia continent drive fault seismogenesis and seismogenesis? This is something that needs attention and research, and reconsideration of the nature of earthquakes and the dynamics that drive them.

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敬告读者

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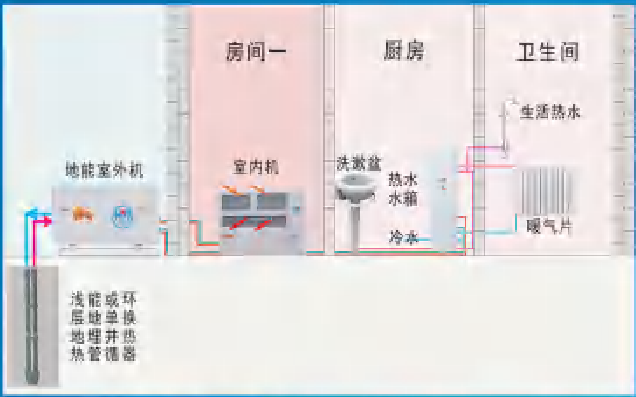

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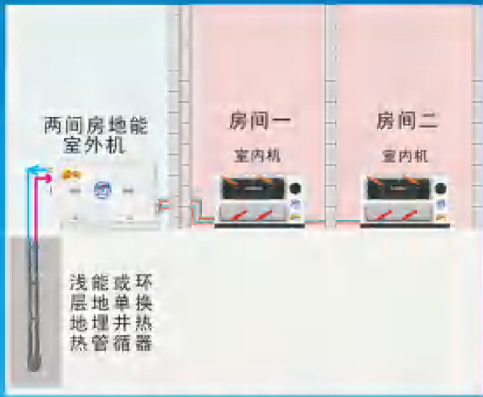

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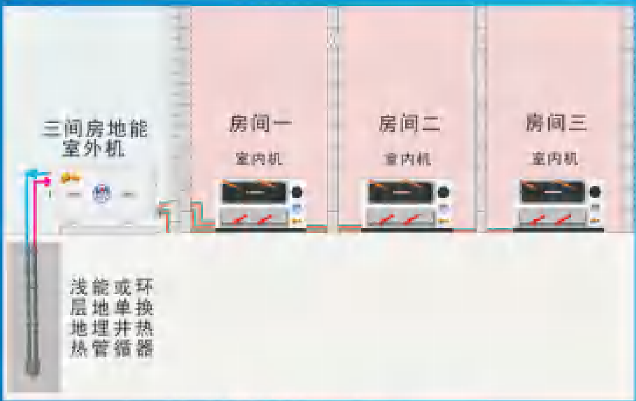

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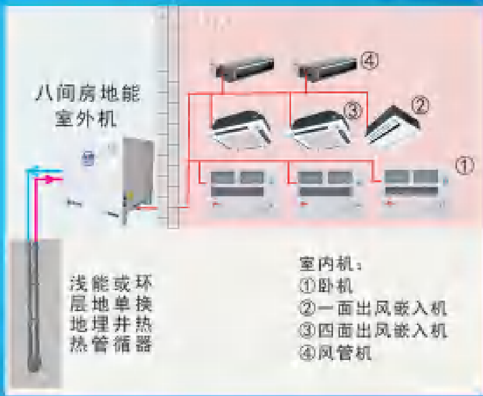

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